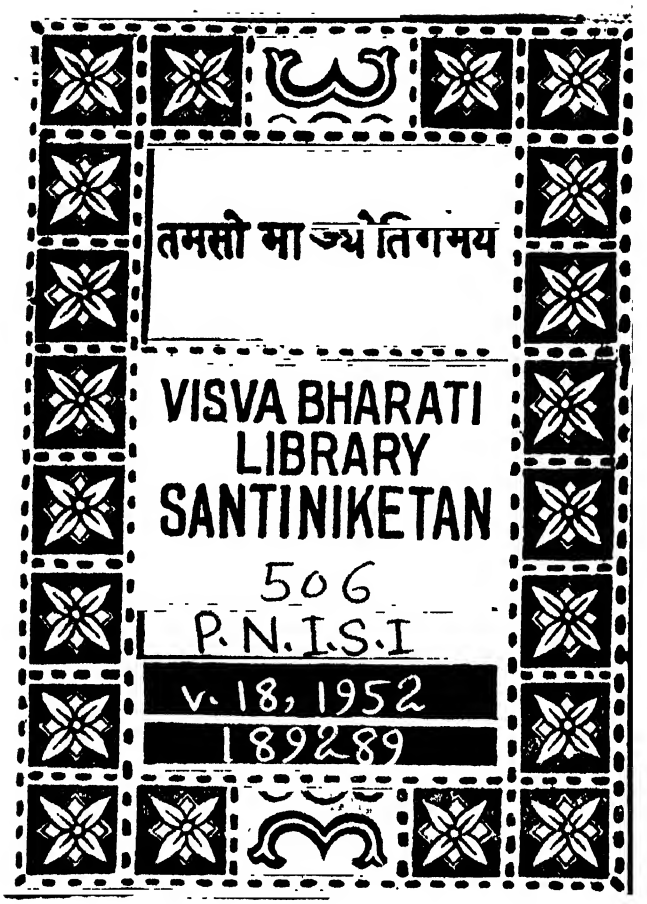
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NOTES ON, AND POSSIBILITIES OF, FERTILIZATION OF FISH PONDS IN INDONESIA.

By K. F. VAAS, *Head of the Laboratory of Inland Fisheries, General Agricultural Research Station, Bogor, Indonesia.*

(Communicated by Dr. S. L. Hora, F.N.I.)

Paper read at the Symposium on 'Organic vs. *Inorganic Manures', held under the auspices of the National Institute of Sciences of India at Bangalore, on 1st January, 1951.*

In Indonesia pond cultivation, as well as rice culture, is carried out by the small farmer on a small scale. The owner or tenant of a pond is usually a simple 'tani' with only limited financial means, although endowed with considerable technical skill. Usually he will be quite unable to expend large sums on fertilizers or manure for use in his ponds. For this reason artificial fertilizers are not used by the Indonesian fish-growers.

In recent years attempts have been made to intensify the fisheries industry by initiating co-operative movements, but as the level of education of the entire population has to be raised for this purpose and, in the first place, more settled conditions than the present are essential, hardly any results have so far been attained.

The above remarks are a necessary preliminary to our considerations on fertilization of ponds since they clearly demonstrate the great difference between the situation in Europe and America and that in Indonesia. For the same reason the use of fertilizers in ponds hardly ever formed the subject of investigation in this country.

Fish cultivation in Indonesia may be divided into the following classes.

1. Culture of the *bandeng* (*Chanos chanos* (*Forsk*)) in brackish-water ponds ('tambaks') situated along the shallow north coast of Java, along the coast of Madura and elsewhere.

2. Culture of common carp, other Cyprinidae and some Labyrinthici in fresh-water ponds, irrigation reservoirs and lakes in Java and elsewhere.

3. Culture of common carp in paddy fields, either simultaneously with, or after the rice.

An increase in the natural food production of the pond being the aim in all methods of fertilization, the principal question is the kind of natural food wanted in each individual case. Moreover, under what environmental circumstances is this food produced in the ponds and how is this food production influenced by cultural practice.

Schuster's monograph on tambaks gives the following data relevant to our purpose.

In brackish-water ponds the depth of the water does not exceed 40–60 cm. As the same applies in most fresh-water ponds we can state that the Indonesian pond is a shallow one. Tambaks are flooded with sea-water together with fresh-water. Consequently, the salt concentration in the water fluctuates between 0 and 260 per mille at various times of the year.

Values between 0 and 50 per mille are most frequent. Consequently, alkalinity is rather high (between 3 and 4·5 c.c. HCl/per litre) and there is no lack of calcium; *p*H values fluctuate between 7·1 and 7·9; the natural buffer capacity of the sea-water preventing greater fluctuations. The average amount of P is of the order of

4·3–6·2 mgr./m.³, which is very minute. Potassium, on the other hand, is abundant. The fresh-water flowing in from the land side contains a fair amount of sediments rich in P and K, but poor in nitrogen (Schuster, 1950).

Fresh-water ponds dug in all kinds of soils and receiving all types of water show a great diversity in environmental factors.

Vaas (1947) gives some analyses.

Nitrogen and Oxygen.

Rain-water contains ammonia and nitrates in amounts varying widely, depending on the amount of these gases present in the atmosphere. Nitrogen compounds in the air are generated by various activities of man (dungheaps, stables, factories). For this reason continuous rain will be less rich than intermittent showers. In Table I, two values both determined in Indonesia but differing rather widely, are given.

Table I.—*Nitrogen content of rain in Indonesia.*

Location.	Year.	Rain in mm. per annum.	$N(NO_3)$-$N(NH_4)$ kg./ha./year.	$N(NO_3)$-$N(NH_4)$ mgr./l.	Author.
Deli ..	1925-1940	2,000	30	1·5	Roelofsen (1941)
Bogor ..	1948-1949	5,000	13	0·26	Baars (1950)

However, as Baars (*l.c.*) pointed out, these large amounts of nitrogen cannot enrich the ponds without heavy losses.

Especially when showers are heavy, most of the water will leave the pond immediately *via* the outlet, and in that case when the pond water contains more nitrogen than the rain, all rain causes a dilution. When investigating nitrogen conditions in paddy fields, Baars found a considerable nitrogen fixation in the soil, firstly in the form of NH_4, which compound is converted into nitrate later on. However, heavy rains wash out a large portion of the nitrates previously formed.

The amount thus fixed and lost again proved to be much larger than the amount consumed by the rice plant during growth. For the rice plant in the paddy field, it is not so much a question of the quantity of nitrogen in the soil but rather of its availability.

It is deemed to be of primary importance to repeat Baars' paddy field investigations in fresh-water ponds, as many environmental factors are different in this case. Most paddy fields are dry during long periods and, even when flooded, conditions for aerobic nitrogen fixation seem to be realized.

Ponds are drained for short periods in between long cultivation periods. A heavy layer of mud containing remains of plants and animals is usually found on the bottom. Formation of H_2S was frequently observed, especially in tambaks where it was found to kill young fry. Detailed observations are lacking, but in tambaks 10–30 per cent saturation of oxygen was found at the surface of the water in the morning, indicating that the amount of oxygen on the bottom must be small indeed. In the mud, however, anaerobic conditions must exist. According to Schuster (unpublished data), anaerobic nitrogen-fixing bacteria of the Clostridium-type occur in tambak mud. However, if we assume an anaerobic fixation by Closteria we cannot assume a nitrification in the same place.

According to Allinson *et al.*, De, and others, whose work was summarized by Fogg (1947), it is highly probable that the dense bottom vegetation of blue-green algae, consisting of such species as *Phormidium*, *Oscillatoria*, *Microcoleus* and *Lyngbia*, living on the mud in contact with both mud and water, is capable of aerobic nitrogen fixation. This was proved for many—unfortunately other—species in paddy fields in India. Thus this layer of bottom algae probably has a double function in Indonesian

tambaks, its function as a food for the bandeng being well established. (Schuster *l.e.*)

The fundamental question as to whether the soil layer of our fresh-water ponds is devoid of oxygen or not still needs experimental elucidation. It is obvious that the answer to this question should be the basis for all fertilization projects. As the oxygen from the water on the bottom must be the principal source for the oxygen in the soil itself, we will describe briefly what is known about the availability of this gas in ponds here. Even in the morning, just before sunrise, when there has been no photosynthesis throughout the night and oxygen-consuming processess have been able to exert their maximal influence, in most cases there proved to be a certain amount of oxygen in the bottom layers of the water. The reason is found in the temperature fluctuations of the water. Fig. 1 (unpublished measurements made by M. Sachlan and I. Zahir) shows the fluctuations of the water temperature at the surface and on the bottom of a pond in Bogor in relation to the temperature of the air. It follows that only during the short period between 11 a.m. and 4 p.m. did the pond show a stratification with a very slight stability (difference in temperature 1° only), and that during the period between 5 p.m. and 9 a.m. the following morning the pond showed an inverse stratification owing to the steep drop in temperature of the air and the strong heat-retaining power of the mud on the bottom. It follows that during this second period the water must be in constant circulation even without any disturbing influence of the wind, as a heavy layer of cold water lies on top of a warmer layer with a lower density. This constant circulation brings about transportation of oxygen from the air to the bottom layers. Buschkiel (1939) investigated the same phenomenon in Javanese ponds with the aid of self-recording apparatus and arrived at similar conclusions.

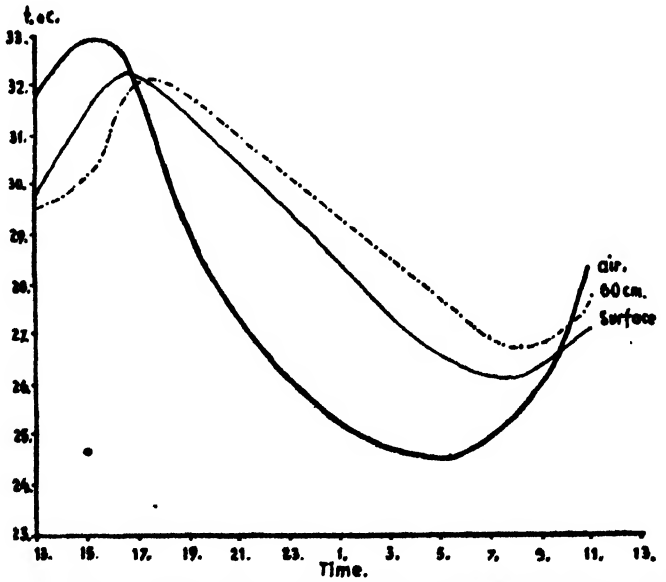

FIG. 1. Daily fluctuations in temperature in a shallow pond in Bogor.

Fig. 2 shows the result of an experiment carried out by the author and M. Sachlan in a pit at Bogor, measuring 2 metres by 1·20 m. in diameter. Compared with Fig. 1, where water having a depth of 60 cm. was measured, we find that the bottom layers do not warm up so much, resulting in a greater difference between surface and bottom temperature. On the bottom of the pit a fair quantity of decaying plant parts was accumulated and for this reason the amount of CO_2 on the

bottom was fairly high, but even then the amount of oxygen did not drop below 3·8 mgr./l., which means a saturation of 48 per cent.

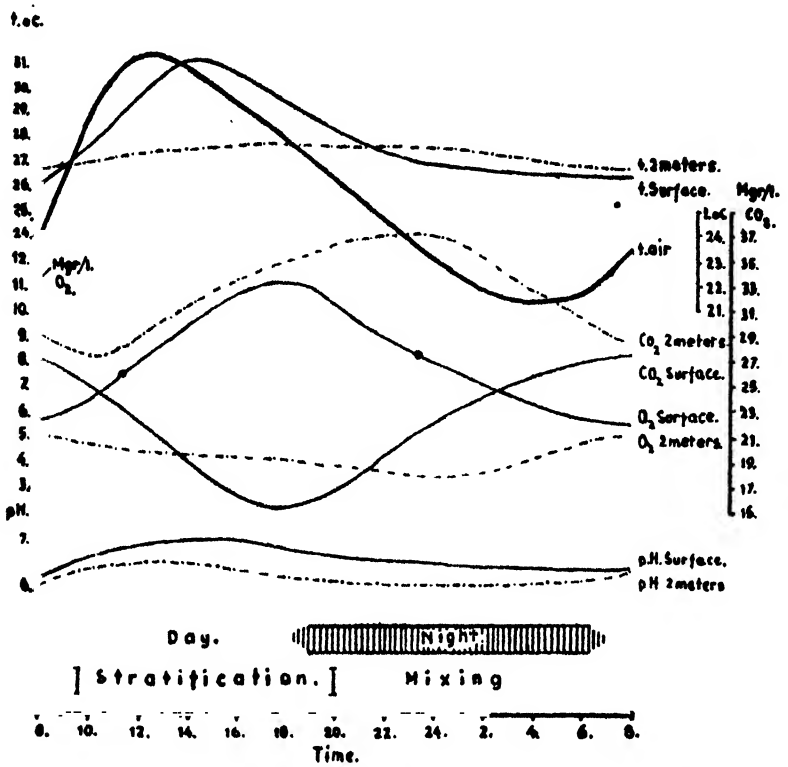

FIG. 2. Daily fluctuations in a 2 m. deep pit in Bogor (Java).

The outstanding importance of the stratification of the water for successful fertilization was recently emphasized again by Cooper and Steven (1948) in a critical review of the well-known experiments on fertilizations, carried out in Lock Craiglin in Scotland, where large amounts of phosphates were used to fertilize a small and shallow sea arm. According to these workers one of the principal reasons why the Scottish investigators did not succeed in making phosphate addition to sea arms an economic process, is to be found in the strong stratification of the water.

As winter conditions do not obtain in the tropics shallow ponds here do not show an annual change-over from a long stagnation period to a period of mixing, but are subject to a daily change instead, as was pointed out by Buschkiel (*l.c.*) and various others. He also mentions that in the upper soil layer of Indonesian ponds there is no pronounced acidification, as drained bottoms show a *p*H between 6·5 and 6·8, which value increases rapidly while the dry pond is exposed to the sun. On the other hand, the investigations of Van Raalte (1941) proved that the rice plants in our paddy fields have to rely on transport of oxygen from the air *via* leaves and stems to their roots. Recently the soils of paddy fields were investigated by Koenigs (1950) and De Gee (1950) at the Agricultural Research Station at Bogor.

The first author examined soil profiles in paddy fields and found that under the ploughpan at a depth of about 20 cm. a layer rich in iron hydroxides and manganese oxides occurred, which layer was formed when, in a reduced state, these metals sank through the topsoil with the water and were oxidized again in the subsoil.

De Gee was able to confirm this hypothesis by means of redox-potential measurements, finding strongly anaerobic conditions in the mud layer and a rise in the redox-potential value of the upper mud surface at a depth of 25–30 cm., precisely at the

depth at which the manganese-oxide layer is found. Fig. 3 shows a simplified picture of the situation. The anaerobic situation is the direct result of the inundation, since in non-irrigated fields there is no drop in redox-potential (broken line in graph). Preliminary experiments in ponds indicated that the mud layer is strongly anaerobic, but in the hard soil under it the redox-potential rises again.

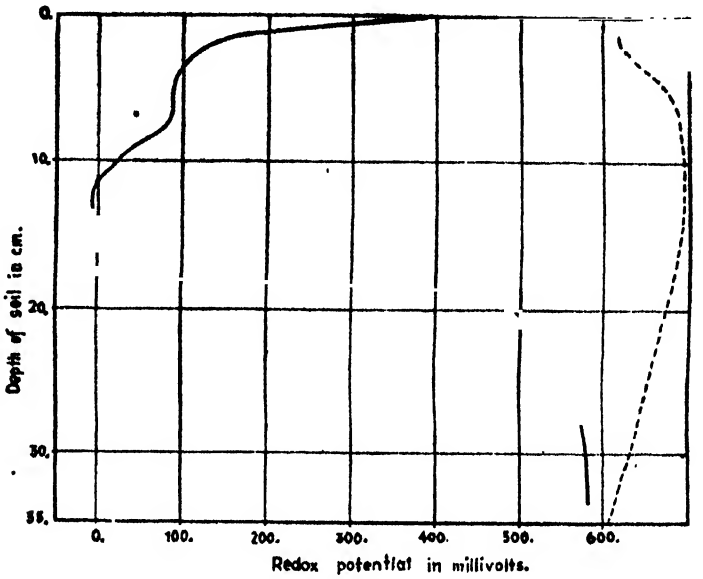

FIG. 3. Redox-Potential in soil of a wet paddy field (solid line), and on a non-irrigated field in the neighbourhood (broken line). After de Gee.

As a result of his elaborate studies on the exchange of minerals between mud and water in English lakes, Mortimer (1941) concluded that the anaerobic phase during stagnation was suitable for mineral exchange, especially of phosphorus, whereas the aerobic circumstances during the annual periods of mixing prevented such exchange because the oxydated iron compounds retained the phosphates.

Summarizing, we can state that we are far from being in a position to judge how organic fertilizers will be affected by environmental conditions in the water and the soil. We cannot yet decide whether the strong N-fixation observed by Baars in paddy fields will occur in ponds, nor are we certain about the leaching out of the nitrates. Thus, although agricultural practice in Indonesia led to the conclusion that nitrogen fertilization in paddy fields did not give good results, we are by no means certain that the same rule applies to ponds.

CARBON DIOXIDE.

Swingle (1947) and many others hold the view that carbon dioxide, the basis of all photosynthesis, may often be a most important minimum factor for production in water. Burr (1941) and others proved that algae have their maximal photosynthesis at carbon-dioxide pressures far exceeding those usually found in natural waters.

This is an important reason why waters with a low calcium content are less fertile. Such waters are unable to hold a sufficient amount of bicarbonate in solution and for that reason the CO_2 pressure is bound to remain low.

Waters deficient in calcium have to rely on diffusion from the air in order to obtain the carbon dioxide necessary for photosynthesis. When such waters are not stirred by the action of the wind, the amount entering by means of diffusion only

must remain very low because, as Burr pointed out, although diffusion of CO_2 occurs about 25 times as rapidly as diffusion of O_2 of the same pressure, the partial pressure of the latter gas in the air is about 700 times as high. Consequently, diffusion must be about 28 times as slow as oxygen diffusion.

When one notices the numerous examples in limnological literature of the slow rate of oxygen diffusion, one should not forget that carbon dioxide is much slower still. As stated above, the water in Indonesian fish ponds is in constant circulation for the greater part of the time. Furthermore, a constant supply of carbon dioxide is provided by the mud and often by the respiration of the zooplankton.

According to Höll (1932), free carbon dioxide would be the only suitable source of carbon for photosynthesis of Peridineae, although the author's observations in Java do not support this statement (Vaas, 1948). Ruttner (1947) found photosynthesis of water mosses (*Fontinales*) with bicarbonate weaker than that with CO_2. On the other hand, many other aquatic plants, such as *Elodea*, were found to consume the bicarbonate freely, thus increasing up to 11 the *p*H of solutions by the action of their photosynthesis.

In Indonesian ponds having a low calcium content, carbon dioxide production on the bottom is in many cases sufficient to maintain a fair concentration even when photosynthesis has reached its maximum. Markus (unpublished data) found the following figures when examining the carbon dioxide in ponds at Bogor, where calcium is low.

TABLE II.—*Carbon dioxide content of a pond in Bogor (after Markus).*

Location.	CO_2 mgr./l. at 10 a.m.	1 p.m.
Surface	7·0	3·4
22 cm.	7·2	4·1
42 cm. (bottom)	8·1	6·2

Fig. 2 also shows an excess of carbon dioxide even during the day. Vaas (1947) examined a number of ponds in the morning in bright sunshine and found an excess of CO_2 in all cases but two, one being a sewage pond in Djogjakarta (*vide* p. 10) the other an eutrophic pond at Tjipanas, where *Osteochilus hasselti* was cultivated.

This pond was fed with warm spring water from young vulcanic soils and supported a dense, submerged growth of *Hydrilla verticellata*. The water was very clear, and photosynthesis was very active.

Only in those cases where the water is extremely rich in calcium and other minerals can CO_2 be a minimum factor in Indonesian ponds, and mobilization of the carbon dioxide supply, tied up in carbonates and bicarbonates, might be considered according to the principles laid down by Swingle (*l.c.*)

For such cases Swingle advocates the use of acid fertilizers or the addition of organic manures which yield acids on decomposition.

PHOSPHORUS.

In contrast to N and CO_2, phosphorus cannot be supplied from the air, therefore conditions must be totally different in the case of this element.

The classical experiments in the German experimental ponds at Wielenbach and Sachsenhausen—valuable sources of information for every investigator in the field in question and comprehensively summarized by Neess (1946) for the benefit of modern American workers—proved that fish crops could be increased at the rate of an additional 2 kg. for every kg. of phosphorus added. According to the German workers we are concerned with the following food-chain. Phosphate → Nitrogen-

fixing bacteria → N and P released from dead bacteria → Blue-green algae (*Anabaena*, later on *Aphanizomenon*) → *Chironomides* and *Tubificidae* on the bottom, burrowing in the soil, *Copepoda* in the water, subsisting on the living and dead blue-greens → Carp.

Following the above principles in recent experiments in America, Swingle (*l.c.*) found a close correlation between the amount of plankton in the water and the crop of *Leptomis macrochir* Raf. Plankton was markedly stimulated by the addition of fertilizers in which the ratios are N : P : K = 4 : 1 : 1. However, since colloidal clay and iron solutions are apt to withdraw a certain amount of phosphorus, a composition of 4 : 2 : 1 gave better results, increasing the production of fish by 200–300 per cent.

The plankton thus stimulated consisted mainly of *Scenedesmus*, *Ankistrodesmus*, *Pandorina* and other *Chlorophyceae* and, to a lesser extent, of *Mycrocystis* as a representative of blue-green algae.

Exactly the same species can be expected under similar circumstances in our ponds. However, it was clearly felt during the course of the above experiments that present knowledge on the physiology and ecology of algae is insufficient, as it is not yet possible to promote or suppress certain groups of algae at will. As Pringsheim (1950) pointed out in a recent article, the methods of pure culture developed by him may prove to be the ultimate solution to these and similar problems.

Light.

Of primary importance for cultivation in Indonesia is the antagonism elucidated by Swingle between the plankton on the one hand and the bottom vegetation—higher plants as well as algae—on the other hand. Although many submerged plants as well as certain algae are able to subsist floating in the water, they begin their life rooted in the soil, be it with the aid of true roots or with rhizoides. For this reason they must take their mineral food mainly from the soil, contrary to the plankton organisms, developing, living and feeding throughout the whole body of the water. The minerals necessary for growth are the same for both groups, in other words if one group manages to get a start, the other will soon be ousted. A dense growth of plankton can decrease the transmission of light to such an extent that the bottom does not receive sufficient light for the plants. For this reason easily soluble fertilizers will stimulate the plankton and damage the bottom vegetation. When the latter vegetation is undesirable, as is the case in various American ponds, fertilizers can be used even for its eradication. In Indonesian carp ponds (*Cyprinus carpio*) a well-developed bottom fauna, which does not depend directly on sunlight, is of much more importance than a bottom flora, and the *Crustaceae* living in the water are an important food for the common carp. It is, therefore, considered highly probable that the use of inorganic fertilizers will increase the yield of ponds where *Cyprinus carpio* or *Helostoma temmincki*, a typical plankton feeder, are the principal species cultivated. The common carp itself brings about a certain turbulence in the water owing to its habit of burrowing and digging in the soil. Thus the bottom vegetation is constantly damaged both directly and indirectly because sunlight is intercepted.

Buschkiel (*l.c.*) divided a glass tank into two equal sections by means of a glass plate. However, the two compartments were not quite watertight. When small carps were allowed to swim in one of the two sections, the water gradually became cloudy as the result of a dense growth of phytoplankton (*Scenedesmus* mainly), the other compartment remaining perfectly clear.

In ponds which must rely on their bottom vegetation for the production of food, conditions are quite different. *Osteochilus hasselti* is cultivated in clear water supporting a dense growth of *Hydrilla verticellata*, because the young leaves and notably their periphyton, are the principal food for that fish.

For *Chanos* the algal vegetation on the mud, composed of blue-greens and diatoms, is the most suitable food, while thread algae originating from the bottom form a danger when they float on the surface, as the malaria-mosquito lays its eggs among the floating masses (*vide* Schuster, *l.c.*). In both cases it is the soil that is to be fertilized and not the water. Swingle found that the bottom vegetation increased enormously when inorganic fertilizer was applied to ponds where the lower water layers were very cold and consequently hardly any mixing with top layers occurred. The same effect was found in the case of organic manures, such as cottonseed meal and ground flour, both heavy, insoluble substances, decaying slowly on the bottom of the pond and thus in the first place providing food for the bottom vegetation. In Indonesian ponds decomposition will be much more rapid and the frequent mixing of the water is also apt to counteract exclusive fertilization of the bottom.

A great disadvantage in the use of fertilizers in Indonesian ponds—even assuming that the owners had been able to find the necessary money—will certainly be the frequent changing of the water inherent to Indonesian practice. In many fresh-water ponds fry is reared up to the fingerling stage only, and fingerlings form the ultimate product sold for the purpose of rearing consumption fish. The growth periods in these ponds may be very brief. When water and soil are very fertile, they may be as short as one month.

Even when the periods are much longer than those just mentioned, water is constantly changed for various purposes, such as counting, landing, eradication of predators and, in the case of the brackish-water ponds, for the capture of prawns. This practice added to the inevitable leaching of the dykes, creates conditions differing entirely from those encountered in temperate climates.

In many Indonesian fresh-water ponds a steady flow of water is maintained, obviously much more than is absolutely necessary to compensate the combined losses of evaporation and leakage. Amounts of 5–10 litres/second/hectare are used. As the inlet and outlet of the pond are both situated in the top layers of the water, it is possible that the whole body of the water is not completely stirred, but what actually happens is that an upper layer of water straight from the inlet moves on towards the outlet without much mixing with the other water layers. On the other hand, we have seen that the fluctuations in daily temperature between the surface and the bottom indicate a high rate of mixing.

In Central Europe the water in carp ponds is not allowed to flow at all, only losses are compensated.

The author is not aware of any experiments carried out in Indonesia designed to compare a minimum water supply with the usual supply. It is understood that a rapid movement of the water is most unfavourable for the development of plankton, the scanty plankton of rivers as compared with lakes being a well-known illustration of this statement, known in limnology as 'Kofoids Law'. Whether a rapid flow through the pond will be a disadvantage from the point of view of the supply of minerals, depends on the relation between the respective mineral content of the water and the soil and on their powers to absorb minerals, or to liberate these substances. In many places in Indonesia the water admitted to the ponds contains much fertile silt.

As the above relations provide, so to speak, the material the fertilizer must use to build up its action, we should do well to defer our judgement until the results of numerous experiments and analyses are available.

The practical side of pond fertilization in Indonesia.

(*1*) *Tambaks*

Fertilizers are not used in our tambaks; experiments on their use have not been conducted.

Stable manure is not used either, as hardly any cattle is raised in the tambak-area. As will be evident from a perusal of the aerial photographs in Schuster's tambak monograph, the tambak area in Java consists of closely serrated groups of ponds, with only a few dykes, canals and huts in between. There is hardly any space left for activities other than fish cultivation. In the case of fresh-water ponds conditions are quite different as these ponds usually lie more scattered between the houses and home gardens.

In brackish-water sewage reservoirs such as the 'Wester boezem' near Surabaja (*vide* Vaas, 1948), a great display of zooplankton in the water was observed. Green manuring of tambaks is a common practice in Indonesia, and experience has taught us that by adding about 2,000 kg. of grass or mangrove-leaves per hectare—piled up in the form of small heaps covered with earth—the formation of blue-green algae on the bottom is stimulated (Schuster, *l.c.*). These findings again are in accordance with Swingle's work. Along the coast vegetation on the dykes is rather poor owing to the salt content of the soil. However, in tambaks situated further inland, where less salt is found in the soil, a dense vegetation of grasses and *Cyperaceae* does occur. These plants may be used to great advantage as green manure, the usual practice again being to pile them up in small heaps showing above the water.

Shortly before the war experiments were started with fertilizers such as copra-slime.

Significant increases in the growth of the fish were noted when applications of 750–1,000 kg./ha. were used.

At the moment similar experiments are being carried out in Macassar, where inorganic fertilizers are also tested. Results are not yet available.

In brackish-water ponds in Formosa, Japanese culturists gained much experience in the application of various kinds of organic manures, such as waste products of fisheries, human faeces, rice polishings, press-residue of cocoanuts and groundnuts.

With applications of about 100 grams/m.^{2}, they were able to produce considerable masses of *Lyngbia* on the bottom of their ponds, on which alga good crops of bandeng subsisted.

The geographic and economic structure of the tambak industry in Java does not permit the use of such methods at the present time.

(2) *Fresh-water ponds*

In Indonesia the owner of practically every pond has built his 'convenience' above it, and a regular but small supply of human faeces is a common feature. For various fish and notably for the common carp, human faeces should not be regarded as a manure only, since it represents a direct food as well. The same applies for all sorts of household and kitchen waste, together with the waste products of home rice polishing thrown into the pond—a common household practice.

Stable and green manure, such as leaves, should be regarded as a fertilizer only. This form of manuring is often used for the very young fry of various species and also for the rearing of *Helostoma temminckii*, as already stated, a typical plankton feeder. A good example is furnished by a Helotoma pond near Tasikmalaja studied by the author.

Five days after a successful spawning 375 kg. leaves, mixed with stable manure were applied to a pond having a surface of 65 m^2. After ten days a further 150 kg. of the same mixture was given and after 15 days another 75 kg. From the tenth day on, the mud on the bottom of the pond was churned up at frequent intervals by the fishermen with a hoe. The same operation has been carried out by Chinese fish-growers from time immemorial. The result of the fertilization is judged by the fish-grower himself according to the colour of the water. When the water is distinctly green the desired result has been attained and no more manure is added. The author noticed a well-developed plankton consisting of *Oscillatoria, Melosira, Diatoma,*

Navicula, Pediastrum, Oedogonium, Difflugia, Crustaceae and *Rotifera*. Periphyton, too, showed fair development. This pond furnishes a good example of an unintentional application of Swingle's principles. If it is desired to stimulate the development of the plankton by means of additions of organic manure, frequent stirring of the bottom layers of the water and the mud provides a suitable means to ensure fertilization of the water. Although no experiments have been carried out in Indonesia, it is likely that in ponds deficient in lime, green manure mixed with lime will give much better results, as was frequently proved in other countries.

An example of the use of stable manure on a big scale is furnished by Lake Tjiburuj. Some years before the war this lake was under the management of the energetic owner of a dairy farm situated in the vicinity of the lake. With a clear insight into the possibilities of fresh-water fish culture this man secured the lease of the lake and started manuring it with his own stable manure and with as much as he could obtain from other sources. The waste products from some small-scale tapioca factories were also thrown into the lake. Fishing was prohibited throughout the year and only permitted on special days at fixed prices. Landings of 2,000 kg./ha. were attained within 7 months. Apart from a favourable economic situation as described above, hydro-biological features of the object in question must also be favourable to obtain similar results. Lake Tjiburuj is rich in lime, has a well-developed shore line and is favourably situated as regards mixing of the water by wind action. For these reasons no fish were ever killed in the course of manuring, as a result of anoxia.

Human faeces in the form of sewage is also used in Indonesia, with the double aim of purification of the sewage and fertilization of the pond. These forms of fish culture were described by the author elsewhere (Vaas, 1948). The situation was summarized in the following words.

'In Djokjakarta part of the effluent of a large septic tank, where the domestic sewage receives its first treatment, is further purified by technical means, the rest mixed with river-water at the rate of 1 : 3 fills a shallow pond of 840 m.[3] According to investigations by Schaeffer, the water discharged has lost all typhoid bacilli, the coli-titer is reduced to 1/100th of its original value, and the amount of organic matter and NH_4 is so much lower as to render the water quite safe to discharge. A mixed crop of fish is raised (*Cyprinus carpio, Puntius javanicus, Trichogaster pectoralis* and *Helostoma temminckii*), giving a yield of 500 kg. a year (about 4,000 kg./ha./year).'

'The microflora was found to consist of Diatoms near the inlet and Diatoms, *Protococcales* and Zooplankton near the outlet.'

In many places the domestic sewage of hospitals and similar large institutions is used to great advantage to fertilize fish-ponds.

In such institutions labour is cheap, sufficient space to dig ponds is usually available, waste products of human society are plentiful, there is much need of a cheap protein food, and the necessary capital is easily furnished by the institution. Reyntjes (1936) described the ponds near the lunatic asylum 'Sumberporrong' at Lawang, where the Fishery Officer J. Hofstee succeeded in raising a mixed crop of common carp and *Puntius javanicus* which yielded 3,000 kg./ha./year and more.

A small amount of disinfectants (creoline) in the sewage did not interfere with fish culture; this is decomposed in the open drains between the asylum and the ponds. Spawning, however, proved to be unsuccessful.

Fertilization of inland waters, such as lakes and large reservoirs, is regarded as a very difficult problem even in America and Europe. In a recent article Hasler and Einsele (1948) emphasized this point. They indicated the high costs, the danger of the occurrence of nuisance blooms of algae on the surface, the shortening of the

[1] This statement refers to the pre-war situation. At the moment the fish-pond is not used.

life-span of the water and the considerable gaps in our theoretical knowledge of the physiology of algae in their natural environment. In the above-mentioned article experiments and investigations are suggested to elucidate this difficult problem. The above-mentioned example of Lake Tjiburuj indicates that, under favourable conditions, good results can be attained in Indonesia.

Huntsman (1948) described a large-scale experiment in fertilization of a river with inorganic fertilizers. Results were not promising because the bottom absorbed too much and, moreover, the stretch affected was rather short. Nevertheless an increased production of algae and fish was observed.

Hitherto river fisheries in Indonesia received hardly any attention at all.

The author is well aware that in the foregoing more questions are put than answers given, more desiderata than data, yet he cherishes the hope that these notes on fertilization may be useful for those who are going to explore this interesting field.

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STABILITY OF STARS UNDER VARIABLE Γ.

By R. S. KUSHWAHA, *Allahabad University, Allahabad and* P. L. BHATNAGAR, *St. Stephen's College, Delhi.*

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1. It is a well-known fact that if Γ, the effective ratio of specific heats of stellar material, is constant throughout the interior of the star, it becomes dynamically unstable for values of $\Gamma < \frac{4}{3}$, being in neutral equilibrium for $\Gamma = \frac{4}{3}$. Ledoux (1946) studied the effect of the variable Γ on the dynamical stability of homogeneous and standard models by taking a central core with $\Gamma = \frac{4}{3}$ and an envelope with $\Gamma = 1$. He found that for dynamical instability to set in the envelope should extend inside the star to the depth at which the temperature is of the order of half the central temperature, that is the ratio of the radius of the core to the radius of the star is approximately 0·727 for the homogeneous model and 0·36 for the standard model. Ledoux has pointed out that peculiar forms of $\Gamma(r_0)$ could increase the instability considerably. In the present note we have studied the stability of the fundamental mode of oscillation of the following two models taking Γ as a function of r_0 giving a continuous decrease in Γ from the centre to the surface of the star.

(i) Homogeneous model.

(ii) The model for which the density varies inversely as the square of the distance from the centre,

with $\Gamma = \Gamma_0 \left(1 - A \frac{r_0^2}{R^2}\right)$,

where r_0 stands for the distance of the point from the centre, Γ_0 for its value at the centre, and R for the radius of the star. A is dimensionless constant. The choice of law is made in such a manner that each model becomes amiable to mathematical analysis without resorting to numerical integration.

In other papers one of the authors (Kushwaha, 1951) has studied the stability of higher modes of oscillation of these two models and the stability of fundamental and higher modes of oscillation of the Roche-model and a model with a central point-mass equal to one-third of the total mass of the star with homogeneous density distribution throughout the star with the other suitable law for the variation of Γ.

2. We have taken continuous variation of Γ to see how the stability of a particular model is affected when in the outer part of the star Γ falls below $\frac{4}{3}$ and to know how the displacement function and the period of pulsation of the star vary with the mean value of Γ for the whole star. Besides, as is evident from the calculations of Fowler and Guggenheim (1925) for giant stars composed of mainly $Fe^{(26)}$ Γ decreases from 1·68 at the centre $z = 0$ to 1·295 at $z = 4$ on the scale when $z = 6{\cdot}9011$ is the radius of the star, meaning thereby that Γ varies more or less continuously.

$\frac{d\Gamma}{dr_0}$ being proportional to A for a given value of r_0 the variation of Γ with r_0 can be arbitrarily chosen. For a small radial adiabatic deformation such that

$$\frac{\delta r}{r_0} = \xi(r_0) e^{i\sigma t}, \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

σ^2 is given by

$$\sigma^2\int_0^R \xi\, dI_0 = -\int_0^R 4\pi\xi r_0^3 \frac{d}{dr_0}[(3\Gamma-4)P_0]\, dr_0, \quad .. \quad .. \quad (2)$$

where the suffix zero refers to equilibrium values. Further more

$$I_0 = \int_0^R r_0^2\, dm, \quad .. \quad .. \quad .. \quad .. \quad .. \quad (3)$$

represents the moment of inertia with respect to the origin and ξ the solution of the differential equation

$$\frac{d^2\xi}{dr_0^2}+\left[\frac{4-\mu}{r_0}+\frac{1}{\Gamma}\frac{d\Gamma}{dr_0}\right]\frac{d\xi}{dr_0}+\left[\frac{\sigma^2\rho_0}{\Gamma P_0}-\frac{\mu}{r_0^2}\left(3-\frac{4}{\Gamma}\right)+\frac{3}{r_0\Gamma}\frac{d\Gamma}{dr_0}\right]\xi = 0, \quad \therefore \quad (4)$$

with the boundary conditions

$$\xi \cdot r_0 = 0 \text{ at } r_0 = 0, \quad .. \quad .. \quad .. \quad .. \quad (5)$$

and

$$\delta P = -\Gamma P_0\left[3\xi + r_0\frac{d\xi}{dr_0}\right] = 0 \text{ at } r_0 = R, \quad .. \quad (6)$$

where

$$\mu = G\frac{mr_0\rho_0}{r_0P_0}, \quad .. \quad .. \quad .. \quad .. \quad (7)$$

and Γ is the general adiabatic exponent defined by

$$dQ = dU - P\frac{d\rho}{\rho^2} = 0, \quad .. \quad .. \quad .. \quad .. \quad (8)$$

the variation of the internal energy dU being expressed in terms of P and ρ. In a star Γ is, in general, a function of the ratio of the pressure of radiation to the total pressure, $(1-\beta)$, of the degree of ionisation and of the number of degrees of freedom of the particles.

3. *Homogeneous Model*

From (2) we shall have definitely a positive value of σ^2 for the fundamental mode ($\xi > 0$ throughout the whole star) if

$$\frac{d}{dr_0}[(3\Gamma-4)P_0] < 0. \quad .. \quad .. \quad .. \quad .. \quad (9)$$

For this inequality to be true we must have

$$0 < A < \tfrac{1}{5}. \quad .. \quad .. \quad .. \quad .. \quad (10)$$

Hence, we can safely predict that at least for values of A given by (10) the star will be stable. We shall consider here the higher values of A and see for what value of A the instability will set in by actually solving the pulsation equation (4).

Writing $x = \frac{r_0}{R}$, we have for this model

$$g_0 = 4\pi G\rho Rx, \quad .. \quad .. \quad .. \quad .. \quad .. \quad (11)$$

$$P_0 = 2\pi G\rho^2R^2(1-x^2), \quad .. \quad .. \quad .. \quad .. \quad (12)$$

$$\Gamma = \Gamma_0(1-Ax^2). \quad .. \quad .. \quad .. \quad .. \quad (13)$$

Substituting values for g_0, P_0 and Γ from (11), (12) and (13) in (4) we get

$$(1-x^2)(1-Ax^2)\xi''+[4-6(A+1)x^2+8Ax^4]\frac{\xi'}{x}+[F+12Ax^2]\xi=0, \quad \ldots \quad (14)$$

where $$F=\frac{3\sigma^2}{2\pi G\rho\Gamma_0}-2\alpha_0-6A, \quad \alpha_0=3-\frac{4}{\Gamma_0}, \quad \ldots \quad \ldots \quad (15)$$

dashes denoting differentiation with respect to x.

Equation (14) has regular singularities at $x=1$ and at $x=\frac{1}{\sqrt{A}}$. We have to find out regular integrals which are finite in the range $0<x<1$ in order that boundary conditions may be satisfied.

The roots of the indicial equation are 0 and -3. To avoid singularity at the centre, we take the first root, and put

$$\xi=\sum_{k=0}^{\infty}a_{2k}x^{2k}. \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (16)$$

Substituting it in (14) and equating the coefficients of various powers of x to zero we have

$$10a_2+Fa_0=0, \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (17)$$

$$(2k+2)(2k+5)a_{2k+2}+[F-(A+1)2k(2k+5)]a_{2k}+[(2k-2)(2k+5)+12]Aa_{2k-2}=0, \quad \ldots \quad \ldots \quad (18)$$

where $k=1, 2, 3, \ldots$.

Writing

$$\frac{a_{2k+2}}{a_{2k}}=N_{k+1}$$

(18) can be put in the form

$$N_{k+1}=\frac{2k(2k+5)(A+1)-F}{(2k+2)(2k+5)}-\frac{A\{(2k-2)(2k+5)+12\}}{(2k+2)(2k+5)}\cdot\frac{1}{N_k}, \quad \ldots \quad (19)$$

$$=(A+1)-\frac{4k+10+F}{(2k+2)(2k+5)}-\left\{A-\frac{(8k+8)A}{(2k+2)(2k+5)}\right\}\frac{1}{N_k}. \quad \ldots \quad (19')$$

Suppose N_k tends to a limit λ when $k\to\infty$. Consequently N_{k+1}, N_{k+2}, ... will all tend to λ. Hence, from (19') we get in the limit

$$\lambda=A+1-\frac{A}{\lambda}. \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (20)$$

The roots of this equation are A and 1.

In case when $N_k\to 1$ the series for ξ diverges for $x=1$. According to our physical conditions, we must choose the solution for which $N_k\to A$, where $A<1$. This restricts us to a determinate set of values of F.

(19) can also be written as

$$N_k=\frac{A\dfrac{(2k-2)(2k+5)+12}{(2k+2)(2k+5)}}{\dfrac{2k(2k+5)(A+1)-F}{(2k+2)(2k+5)}-N_{k+1}}, \quad \ldots \quad \ldots \quad (21)$$

and by successive application of (21) we can express N_k in the form of a convergent continued fraction,

$$N_k = \cfrac{A\dfrac{(2k-2)(2k+5)+12}{(2k+2)(2k+5)}}{\dfrac{2k(2k+5)(A+1)-F}{(2k+2)(2k+5)}-\cfrac{A\dfrac{2k(2k+7)+12}{(2k+4)(2k+7)}}{\dfrac{(2k+2)(2k+7)(A+1)-F}{(2k+4)(2k+7)}-\cfrac{A\dfrac{(2k+2)(2k+9)+12}{(2k+6)(2k+9)}}{\dfrac{(2k+4)(2k+9)(A+1)-F}{(2k+6)(2k+9)}-\ddots}}} \quad \ldots \quad (22)$$

In particular it will give N_1. Also from (17) we get

$$N_1 = -\frac{F}{10}. \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (23)$$

Hence, equating the two values of N_1 we have

$$\frac{F}{10}+\cfrac{\frac{12}{28}A}{\frac{14(A+1)-F}{28}-\cfrac{\frac{30}{54}A}{\frac{36(A+1)-F}{54}-\cfrac{\frac{56}{88}A}{\frac{66(A+1)-F}{88}-\ddots}}} = 0. \quad \ldots \quad (24)$$

This equation determines the values of F, which ultimately gives the value of σ, the frequency of oscillations. The coefficients a_2, a_4, a_6, ... in (16) are given by

$$a_{2r} = \prod_1^r (N_s)a_0. \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (25)$$

Here it is to be noticed that the successive constant coefficients for the series for ξ are not obtained from the relation (18) as this would require us to start with exactly the right value of F and to observe absolute accuracy in the subsequent stages of the work, otherwise calculation will lead to the values of N_k which approximate to the limit unity (Lamb, 1916).

The approximate solution of (24) was carried out as follows. Choosing different values of F we drew a graph for the relation (23). Also for different values of F we calculated N_5 from (22) by successive convergents approximately, and thereby obtained N_1 from (21). Again we drew an other graph for these values of N_1 and F. The point of intersection of these two graphs gives the approximate solutions of (24).

We have considered the variation of Γ given by $A = 0{\cdot}1$, $0{\cdot}2$, $0{\cdot}3$, $0{\cdot}4$ and $0{\cdot}5$. The results are collected in Table I in which x_c denotes the value of x such that $\Gamma < \frac{4}{3}$ for $x_c < x < 1$, and the displacement functions for these different values of A are given below.

$A = 0{\cdot}1$, $\xi = a_0\{1+0{\cdot}08626x^2+0{\cdot}007215x^4+0{\cdot}0006137x^6+0{\cdot}0000532x^8+\ldots\}$.

$A = 0{\cdot}2$, $\xi = a_0\{1+0{\cdot}1735x^2+0{\cdot}02915x^4+0{\cdot}00497x^6+0{\cdot}000865x^8+\ldots\}$.

$A = 0{\cdot}3$, $\xi = a_0\{1+0{\cdot}262x^2+0{\cdot}0673x^4+0{\cdot}01705x^6+0{\cdot}004459x^8+\ldots\}$.

$A = 0{\cdot}4$, $\xi = a_0\{1+0{\cdot}3525x^2+0{\cdot}1197x^4+0{\cdot}053197x^6+0{\cdot}01865x^8+\ldots\}$.

$A = 0{\cdot}5$, $\xi = a_0\{1+0{\cdot}4458x^2+0{\cdot}19092x^4+0{\cdot}08283x^6+0{\cdot}03662x^8+\ldots\}$.

TABLE I.

A	F	$y=\frac{3\sigma^2}{2\pi G\rho\Gamma_0}$	$\bar{\Gamma}=\int_0^1 \Gamma dx=\Gamma_0\left(1-\frac{A}{3}\right)$	Γ_{surface}	x_c
0·1	−0·8626	0·9374	1·61	1·5	—
0·2	−1·735	0·665	1·555	1·333	1
0·3	−2·62	0·38	1·5	1·166	0·817
0·4	−3·525	0·075	1·444	1·00	0·707
0·5	−4·458	−0·258	1·3889	0·8333	0·634

The instability sets in when $x_c \approx 0{\cdot}684$ and $\bar{\Gamma} \approx 1{\cdot}43$. Whereas the instability in the homogeneous two-phase model studied by Ledoux and described in §1 sets in when $\bar{\Gamma} \approx 1{\cdot}485$. It appears that by taking the continuous variation in Γ the stability is increased in the sense that the model remains vibrationally stable for much lower value of average Γ. In fact for constant Γ throughout the model it is vibrationally stable as long as $\Gamma > \frac{4}{3}$ but even if we take a small continuous variation in Γ as in the present case, the model becomes vibrationally unstable for much higher value of average Γ, namely $\bar{\Gamma} \sim 1{\cdot}43$ and instability is further increased if the variation in Γ is discontinuous as in the case of Ledoux's treatment.

4. *Inverse square model.*

In this case also we see from (2) that for fundamental mode σ^2 will be definitely positive for values of A in the range $0 < A < \frac{1}{3}$. We consider the effect of higher values of A on the dynamical stability.

For this case

$$\left.\begin{aligned} \Gamma &= \Gamma_0(1-Ax^2) \\ \rho_0 &= \frac{\bar{\rho}}{3x^2} \\ P_0 &= \frac{2\pi G R^2 \bar{\rho}^2}{9}\cdot\frac{1-x^2}{x^2} \\ g_0 &= \frac{4\pi G\bar{\rho}R}{3}\cdot\frac{1}{x} \end{aligned}\right\} \quad \ldots \quad \ldots \quad \ldots \quad (26)$$

Substituting values of g_0, ρ_0, P_0 and Γ from (26) in (4) we get with the previous notations

$$(1-x^2)(1-Ax^2)\xi'' + [2-4(A+1)x^2+6Ax^4]\frac{\xi'}{x} + [Fx^2-2\alpha_0+6Ax^4]\frac{\xi}{x^2} = 0, \quad (27)$$

where

$$F = \frac{3\sigma^2}{2\pi G\bar{\rho}\Gamma_0}. \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (28)$$

We shall again restrict ourselves to the solutions which are regular and finite in the region $0 \leq x \leq 1$.

The roots of the indicial equation are

$$m = \tfrac{1}{2}[-1 \pm \sqrt{1+8\alpha_0}]. \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (29)$$

Consistent with our physical conditions we choose positive sign before the radical and substitute

$$\xi = x^m \sum_{k=0}^{\infty} b_{2k} x^{2k}, \qquad .. \quad .. \quad .. \quad .. \quad (30)$$

in (27) and as before we get the relations for different constant coefficients as

$$\{(m+2)(m+3)-2\alpha_0\}b_2-\{(A+1)m(m+3)-F\}b_0 = 0, \qquad .. \quad (31)$$

$$\{(m+2k+2)(m+2k+3)-2\alpha_0\}b_{2k+2}-\{(A+1)(m+2k)(m+2k+3)-F\}b_{2k}$$
$$+\{(m+2k-2)(m+2k+3)+6\}A\,b_{2k-2} = 0, \quad (32)$$

where $k = 1, 2, 3, \ldots$.

Putting $\frac{b_{2k+2}}{b_{2k}} = N_{k+1}$ we get

$$N_{k+1} = \frac{(A+1)(m+2k)(m+2k+3)-F}{(m+2k+2)(m+2k+3)-2\alpha_0} - \frac{A\{(m+2k-2)(m+2k+3)+6\}}{(m+2k+2)(m+2k+3)-2\alpha_0} \cdot \frac{1}{N_k}. \quad (33)$$

Again we see here that N_k tends to either A or unity as k tends to infinity. We have to consider the solutions for which $N_k \to A(<1)$ only.

Rewriting (33) as

$$N_k = \frac{A\dfrac{(m+2k-2)(m+2k+3)+6}{(m+2k+2)(m+2k+3)-2\alpha_0}}{\dfrac{(A+1)(m+2k)(m+2k+3)-F}{(m+2k+2)(m+2k+3)-2\alpha_0} - N_{k+1}}, \qquad .. \quad .. \quad (34)$$

we express N_k in the form of a continued fraction.

$$N_k = \cfrac{A\dfrac{(m+2k-2)(m+2k+3)+6}{(m+2k+2)(m+2k+3)-2\alpha_0}}{\dfrac{(A+1)(m+2k)(m+2k+3)-F}{(m+2k+2)(m+2k+3)-2\alpha_0} - \cfrac{A\dfrac{(m+2k)(m+2k+5)+6}{(m+2k+4)(m+2k+5)-2\alpha_0}}{\dfrac{(A+1)(m+2k+2)(m+2k+5)-F}{(m+2k+4)(m+2k+5)-2\alpha_0} - \cfrac{A\dfrac{(m+2k+2)(m+2k+7)+6}{(m+2k+6)(m+2k+7)-2\alpha_0}}{\dfrac{(A+1)(m+2k+4)(m+2k+7)-F}{(m+2k+6)(m+2k+7)-2\alpha_0} - \ldots \text{ etc.}}}} \qquad .. \quad (35)$$

In particular obtaining N_1 from this and equating to its value from (31) we get

$$\frac{F-(A+1)m(m+3)}{(m+2)(m+3)-2\alpha_0} + \cfrac{A\dfrac{m(m+5)+6}{(m+4)(m+5)-2\alpha_0}}{\dfrac{(A+1)(m+2)(m+5)-F}{(m+4)(m+5)-2\alpha_0} - \cfrac{A\dfrac{(m+2)(m+7)+6}{(m+6)(m+7)-2\alpha_0}}{\dfrac{(A+1)(m+4)(m+7)-F}{(m+6)(m+7)-2\alpha_0} - \ldots}} = 0. \qquad .. \quad .. \quad (36)$$

We solved this equation approximately as before and coefficients are obtained by the relation (25).

Here we considered the variation of Γ for $A = 0{\cdot}1$, $0{\cdot}3$, $0{\cdot}5$ and $0{\cdot}6$. The results are given in Table II. The displacement functions for these values of A are given below.

$$\left.\begin{aligned}
A = 0{\cdot}1,\ \xi &= a_0 x^m\{1+0{\cdot}07869x^2+0{\cdot}006335x^4+0{\cdot}0005253x^6 \\
&\qquad +0{\cdot}0000448x^8+\ldots\}. \\
A = 0{\cdot}3,\ \xi &= a_0 x^m\{1+0{\cdot}2409x^2+0{\cdot}05932x^4+0{\cdot}01488x^6+0{\cdot}00385x^8+\ldots\}. \\
A = 0{\cdot}5,\ \xi &= a_0 x^m\{1+0{\cdot}4153x^2+0{\cdot}1754x^4+0{\cdot}07474x^6+0{\cdot}0328x^8+\ldots\}. \\
A = 0{\cdot}6,\ \xi &= a_0 x^m\{1+0{\cdot}5079x^2+0{\cdot}2606x^4+0{\cdot}1336x^6+0{\cdot}0706x^8+\ldots\}.
\end{aligned}\right\} \quad (37)^*$$

TABLE II.

A	$F=\frac{3\sigma^2}{2\pi G\bar{\rho}\Gamma_0}$	$\bar{\Gamma}=\int_0^1 \Gamma\,dx=\Gamma_0\left(1-\frac{A}{3}\right)$	Γ_{surface}	x_c
0·1	2·175	1·61	1·5	—
0·3	1·2665	1·5	1·166	0·8
0·5	0·2508	1·3889	0·8333	0·63
0·6	−0·303	1·333	0·6667	0·577

The instability sets in when $x_c \approx 0{\cdot}606$ and $\bar{\Gamma} \approx 1{\cdot}364$.

A comparison of these values of x_c and $\bar{\Gamma}$ with those for the homogeneous model will show that for the same law of variation of Γ, this model is more stable than the homogeneous model.

Our best thanks are due to Prof. A. C. Banerji for his keen interest in the preparation of this paper.

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* *Note*:—In the similar equations of the other paper by the author quoted in the reference (*a*) the series within the brackets must be multiplied by x^m.

NATIONAL INSTITUTE OF SCIENCES OF INDIA

Seventeenth Annual General Meeting

The Seventeenth Annual General Meeting of the Institute was held at 2-30 p.m. on Friday, 5th October, 1951, in the hall of the Institute, Mathura Road, New Delhi.

Present: Dr. S. L. Hora, *President (in the Chair)*.
Dr. H. S. Pruthi, *Secretary*.

Prof. S. P. Agharkar.
Prof. S. L. Ajrekar.
Prof. S. K. Banerji.
Dr. J. L. Bhaduri.
Dr. P. N. Bhaduri.
Prof. S. Bhagavantam.
Prof. Y. Bharadwaja.
Prof. S. R. Bose.
Dr. K. A. Chowdhury.
Prof. B. B. Dey.
Dr. H. Gupta.
Mr. S. Gupta.
Dr. Robert Heilig.
Dr. P. V. Krishna Iyer.
Prof. R. C. Majumdar.
Dr. K. Mitra.
Dr. B. Mukerji.
Dr. B. B. Mundkur.
Dr. L. A. Ramdas.
Dr. J. C. Ray.
Prof. J. M. Sen.
Prof. T. R. Seshadri.
Dr. M. B. Soparkar.
Dr. P. L. Srivastava.
Dr. A. C. Ukil.

Besides these Fellows of the Institute, there were several visitors present.

1. The minutes of the Fifty-eighth Ordinary General Meeting, held on the 3rd and 4th August, 1951, were confirmed.

2. Dr. P. V. Krishna Iyer was admitted as an Ordinary Fellow under provisions of Rule 13.

3. The Secretary presented the Report of the Council for the year 1950-51 (*vide* page 33).

The Report was accepted.

4. The President then delivered the Annual Address reviewing the work of the Institute (*vide* page 27).

5. The following papers were taken as read as the authors were not present:—

(1) *Studies on Foliar Sclereids in Dicotyledons IV. Structure and Development of Sclereids in the leaf of Ternstroemia Japonica.* By T. Ananda Rao and communicated by Prof. P. Maheshwari.

(2) *A contribution to the life-histories of* Stellaria Media Linn. and Polycarpon Loeflingiae. By Niranjan Pal and communicated by Dr. I. Banerji.

(3) *Studies on South Indian Fusaria I. Fusarium vasinfectum* Atk. *with a note on its varieties and forms.* By C. V. Subramanian and communicated by Dr. M. O. P. Iyengar.

(4) *Further observations on directional changes in locusts and other short-horned grasshoppers (Insecta: Orthoptera: Acrididae) and the importance of the third instar.* By M. L. Roonwal.

(5) *Variation and post-embryonic growth in the number of antennal segments in the* phadka *grasshopper* (Hieroglyphus nigroreplotus *Bolivar*), *with remarks on the Desert Locust and other Acrididae (Insecta: Orthoptera).* By M. L. Roonwal.

(6) Studies on cyto-chemistry of hormone action Part X. *The hormonal modification of alkaline phosphatase activity in the testis and in some genital accessories of the guinea-pig.* By A. B. Kar *and* Asok Ghosh and communicated by Dr. B. Mukerji.

(7) *On the Minimax Approach to the Problem of Estimation.* By D. Basu and communicated by Prof. S. N. Bose.

(8) *An Algal Flora from the Laki (Lower Eocene) Beds of the Nammal Gorge (Punjab Salt Range)—1. Archaeolithothamnium.* By C. P. Varma and communicated by Dr. S. R. N. Rao.

(All these papers have been recommended for publication in the *Proceedings* of the Institute.)

6. A Symposium on 'Antibiotics' organized by Dr. B. Mukerji was held. Several papers were read and discussed.[1] The Symposium continued also on Saturday, the 6th October, from 11 a.m. to 1 p.m.

In the afternoon of the 6th October, 1951 (at 4-30 p.m.) the Hon'ble Shri Sri Prakasa, Minister, Ministry of Natural Resources and Scientific Research, formally opened the new building of the National Institute of Sciences of India, the foundation stone of which had been laid by the Hon'ble Pandit Jawaharlal Nehru, Prime Minister of India, on the 19th April, 1948, on the land granted by the Government of India.

In inviting the Hon'ble Shri Sri Prakasa to declare the building open, the President said:—

THE HON'BLE SHRI SRI PRAKASA, FELLOWS OF THE INSTITUTE, LADIES AND GENTLEMEN.

Today we have met to celebrate an important event in the history of the National Institute of Sciences of India. The Institute is about to make its formal entry into its own new building. On such an occasion one's mind runs back both to the events which led up to the birth of the Institute and to the years that witnessed its growth. Hence I feel that it may be of interest to summon up brief memories of the past.

At a meeting of the Indian Science Congress Association held at Bombay in 1934, it was realized that there was a need for the founding of a Scientific body of eminent scientists of the country to act as a central and all-India co-ordinating body, embracing all scientific research in the country. The Science Congress supported the idea and set up an Academy Committee to draw up a plan for the founding of such a body. On the recommendations of this Committee, the Institute came into being and it was inaugurated at Calcutta on the 7th January, 1935, with its headquarters in the rooms of the Asiatic Society. Thanks to the efforts of our earlier Presidents and successive Councils, the Institute was able to weather many storms and the War years saw us firmly established and fairly well off from our own resources with only a small grant from Government Funds. However, our efforts and earnestness were rewarded when Prof. A. V. Hill, during his visit to India in 1943-44, advised the Government to recognize the Institute as the premier scientific organization in the country and to establish with the Institute liaison similar to that which exists between the Royal Society of London and His Majesty's Government in the U.K. Negotiations between the Government and the Institute followed and it was not until 1945 that the Institute was accorded by the Government the recognition of being the premier scientific organization in the country.

Among the important terms negotiated with the Government one was that Delhi should be the Headquarters of the Institute. The Government wanted the name to be changed to 'Academy of Sciences of India', but as the majority of the Fellows were against this change, the Government did not press for it.

The year 1945, proved auspicious for the Institute in one other respect also, for in that year the Imperial Chemical Industries (India) Limited placed a sum of Rs.3,36,000 for the establishment of Research Fellowships for Physics, Chemistry and Biology according to a scheme covering a period of 7 years.

The University of Delhi, having agreed to provide the Institute some temporary accommodation in its building, the Institute shifted from Calcutta in 1946, but retaining the Publication Office there. The Government very kindly made a

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[1] The proceedings of the Symposium will be published separately in the *Bulletin* of the Institute.

non-recurring grant of Rs.2,20,000 for the building of the Institute, but when the plans were prepared according to the requirements of the Institute the cost worked out at about Rs.5,00,000. Our intention was to provide a Lecture Hall, a Council Room, a Library Hall and the usual office accommodation. It was also intended to have a few rooms set apart as a Faculty-Club where scientists of eminence visiting India from abroad could stay for a limited period. On the model of the Burlington House in London, it was also our intention to provide in our building accommodation to other learned Scientific Societies of India. We had also a plan to run a Science Museum. Owing to financial stringency, the Government asked us to construct the whole building with the allotted sum of Rs.2,20,000 with the result that a part of the building, meeting our minimum immediate requirements, is put up and even for this construction we have overspent a sum of about Rs.50,000 for which an additional grant had to be sought.

The Institute wanted 5 acres of land but only 3 acres were allotted in 1948. The foundation stone of the building was laid by our Prime Minister on 19th April, 1948, but the delay in the construction of the building has been due to some regrettable circumstances beyond the control of the Institute. We recall with grateful thanks the kindness of Mr. S. Khurshid Ahmed Khan, the then Chief Commissioner of Delhi, Mr. M. S. Randhawa, one of our Fellows and the then Deputy Commissioner of Delhi and Mr. A. W. H. Dean, the then Chairman of Delhi Improvement Trust for being helpful to us in the allotment of this plot. Dr. S. S. Bhatnagar, one of our past Presidents, has been helpful to us in so many ways that we cannot, of course, forget his services to the Institute. Mr. G. B. Mhatre of Bombay was selected the Architect for the building by Prof. H. J. Bhabha and Major-General S. S. Sokhey, and the contract for the building was given to Sardars Partap Singh and Ajit Singh, a well-known firm of contractors of Delhi. Our contractors have been very accommodating and helpful in spite of many difficulties and made special efforts to have the building ready for occupation in time for holding our Statutory Meeting in the first week of October.

In inviting you, Sir, to declare the new building open, the Institute takes special pride, for within a few months of your assuming the office of Minister for the new ministry of Natural Resources and Scientific Research you have already shown your great sympathies with scientific development in the country. It is our earnest hope that under your patronage and wise guidance, scientific research in India will progress from day to day and that the Institute will be able to play a leading rôle in such development. The Institute is grateful to you for having spared the time to attend this function and to consent to our request for opening the building. I request you, Sir, to declare the building open.

In reply the Honble Minister addressed the gathering as given below.

Speech by the Hon'ble Shri Sri Prakasa.*

Declaring open the building of the National Institute of Sciences of India, New Delhi, on Saturday, October 6, 1951, the Hon'ble Shri Sri Prakasa, Minister for Natural Resources and Scientific Research, said to the assembled gathering, that he felt very greatly honoured at having been invited formally to open the new building of the National Institute of Sciences of India; and though he could lay no claim to any knowledge of science beyond what was possessed by any schoolboy, he had been, curiously enough, called upon by the Prime Minister, to be in charge of the Ministry that deals with the higher branches of scientific knowledge; and is thus brought in daily contact with learned scientists and experts in varied branches

* The speech of the Hon'ble Minister, Shri Sri Prakasa, was delivered extempore and had not been taken down by any shorthand reporter at the time it was delivered. Therefore, only an abstract is given here.

of science. He was grateful for the honour that had been done him by the President and Fellows of the National Institute, by inviting him to inaugurate the function.

Referring to the speech of the President of the Institute, Shri Sri Prakasa said that he had learnt with much interest the history of the Institute from the lips of the learned President, and regretted with him that despite the ambitious plans that had been made, the implementation of the same had not been possible owing to financial stringency. He felt, however, that even if we could not have larger and more imposing buildings and busy laboratories, our men of science could help in the inculcation of the scientific spirit in the general mass of the people, for it was essential that men and women should have a scientific outlook. He also hoped that when better times returned, the authorities of the Institute would be able to fulfil their ambitions in the matter of science museum, lecture hall and other requirements.

Referring to the President's remarks regarding the attractions of administrative jobs which took away eminent scientists because of better pay and prospects, Shri Sri Prakasa felt sad that that should be so. It was indeed a pity, he said, that in the modern world, administrators enjoyed a higher position than men of learning though that was against the ancient traditions of the land. In the days of long ago, he said that the learned man, however poor, was given a place of honour higher than that of the ruler, however powerful; and that compensated the man of learning, for he got in honour what he lost in money. It was unfortunate that today the administrator should enjoy both pelf and position; and so it was natural that the scientist should seek to be an administrator though he knew that this meant a great sacrifice on his part, for his real work was thus woefully dislocated and interfered with. There were exceptions—and he had such exceptions in the eminent men in his own Ministry—who could be both good administrators and good scientists; who could keep all their files up-to-date as well as be abreast of advancing knowledge.

Such persons, however, could be very few, he added; and said that if Society did not make better arrangements, it would have to suffer from a large number of scientists and men of learning losing their individuality and giving up the work for which they were eminently fitted, by accepting administrative positions. He had however every sympathy with what the President had said, and hoped that the Government and the people alike would see to it that every consideration was made to the needs and requirements of the scientist so that he could carry on his work without any disappointment or dismay. He added that when he was saying this, he was not minimizing the importance of administration which was in itself a great thing; but what was needed, was a proper adjustment of values and the proper fitting of human beings in places for which they were most suited.

According to the traditions of old, Shri Sri Prakasa added, to which he could not help paying his allegiance, Government was not allowed to interfere or meddle with the growth of science and knowledge which was left to the men of learning and the men of science. In the present day, Government was taking on itself more and more work and was prone to interfere in departments of national activity where perhaps the effort of the private individual was more helpful. So far as he knew, many of the greatest discoveries and inventions of science which have revolutionized the lives of men and of nations, have been made not under the patronage of Government or in the laboratories established by them, but in small places by small men working with love and devotion at their tasks. He hoped that this great tradition will not die in India at least, and the great race of learned scientists doing their independent work unaided and undisturbed, will continue.

In the end, Shri Sri Prakasa pleaded with the scientists, to hand on their knowledge from generation to generation, and not make it some sort of a close secret with themselves. It was a pity, he said, that in India persons who have anything special to contribute, keep their knowledge to themselves, and do not teach what they know to others, with the result that important and essential items

of knowledge die with them, and the generations that follow, have to discover and invent the same things over and over again. All progress therefore comes to a stop.

We, in India, he concluded, must learn from the West this great art of generously distributing, so to say, the knowledge that each man possesses for the good of all. He expressed his great delight that Scientific Institutes were doing such good work, and he offered his very best wishes for the health and happiness of all those who were engaged in them. He hoped most sincerely that the general public will realize the value of this work; and when Government, because of its manifold difficulties, is unable to offer financial assistance to such institutions, persons will be found in adequate numbers, who would place sufficient funds at the disposal of scientists and scientific institutions, for the advancement and promotion of scientific knowledge, which will redound to the glory of those who have helped and, at the same time, prove beneficial in the enhancement of the lives and the promotion of the welfare of mankind.

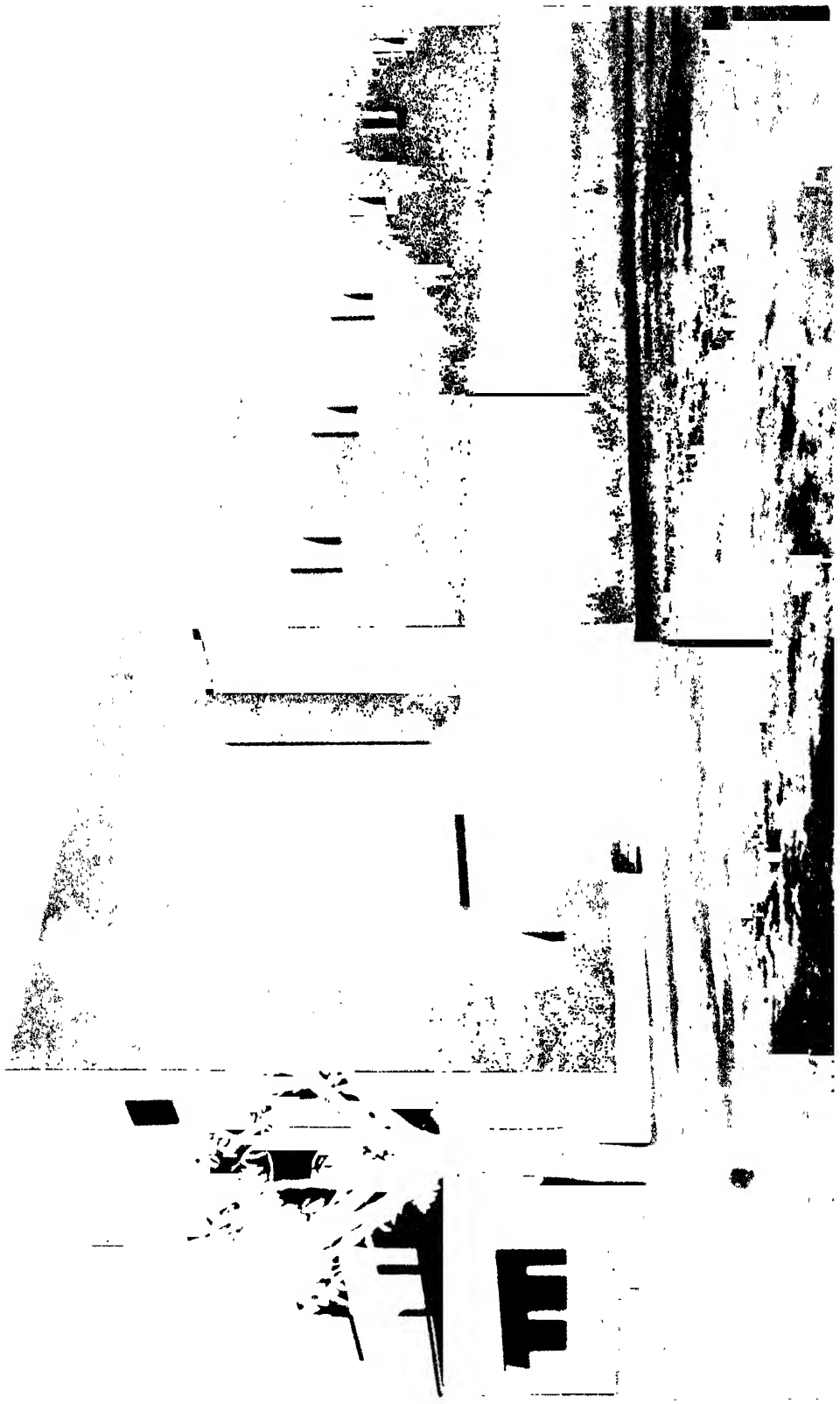
The Hon'ble Minister then declared the building open.

The President thanked the Hon'ble Minister for opening the building, and the Fellows and guests for their presence on the occasion.

The Hon'ble Minister then walked to the entrance door of the building and cut the tape that stretched across it.

On entering the building the Hon'ble Minister signed the Visitors' Book and went round the building with Fellows and guests.

All guests and Fellows were then entertained to light refreshments.



ANNUAL PRESIDENTIAL ADDRESS.

At the Annual General Meeting of the National Institute of Sciences of India, the President is expected to make remarks reviewing the work of the Institute during the year and not to deliver an address on a theme bearing upon his own science. My task has been made easier this afternoon, firstly because the Report of the Council has already given you a summary of the working of the Institute during the year and secondly because three major events of a very pleasant nature happened during the year which are like milestones in the progress of Science in India and which affect the Institute very intimately. Before I deal with these events, it is my first and most pleasant duty to thank the Fellows of the Institute for the great honour they did me in electing me as their President for 1951.

In inaugurating the Institute on the 7th January, 1935, His Excellency Sir John Anderson, the then Governor of Bengal, referred to the sequence of events which brought into being the National Institute. The first organised step for correcting tradition by observation of nature may be said to date in India from the foundation of the Asiatic Society in 1784. The second step dates from 1857 when the Calcutta University, followed at short intervals by a number of other Universities, was founded. The second step also comprised the establishment of a series of great scientific surveys. The third step was the meeting of the Indian Science Congress for the first time in 1914. The fourth step was the inauguration of the National Institute of Sciences of India in 1935 as a central and all-India co-ordinating body, embracing all scientific research in this great country of ours. The establishment of a number of National Laboratories for fundamental researches in various branches of science showed that accelerated evolution in the progress of science was being maintained. The fifth step has now been taken in 1951 in the establishment of a separate Ministry in the Union Government for Natural Resources and Scientific Research, with one of our past Presidents, Dr. Shanti Swarup Bhatnagar, as its first Secretary. This is an event of great importance to Indian scientists in general, and to the Institute in particular. As President of the Institute, I have already conveyed to the Union Government the deep sense of gratitude of the Indian scientists at this most auspicious event in the history of science in India, and have congratulated Dr. Bhatnagar for his wonderful achievements in developing science in India and on the distinction of his being the first Secretary of the new Ministry. In passing, it may be mentioned that the Election Manifesto of the Indian National Congress contains an assurance that adequate measures will be taken to continue unchecked the progress made in scientific researches and in the application of science to industry. The present Congress Government in the centre is rightly proud of the efforts it has made in according a high place to scientific research and development in the country. We are all greatly indebted to our Prime Minister, who is also a Fellow of the National Institute of Sciences of India, for his kind thought and care of science in India.

We are fortunate in having an erudite scholar and a person with broad sympathies as our first Minister for the Ministry of Natural Resources and Scientific Research. Under the patronage of the Hon'ble Shri Sri Prakasa, scientific knowledge and learning are bound to flourish. Through his wise guidance, we hope India will 'promote and maintain a liaison between Science and Letters', one of the objects of founding the National Institute of Sciences of India. On behalf of the Institute and myself, I have already extended to him our fullest co-operation in developing science in the country.

From the time intervals between the various events in the onward march of ence, 1784, 1857, 1914, 1935 and 1951, it will be seen that the progress of science

in our country has been gradual in the past but now its pace is accelerated. Biologically speaking, this evolutionary process signifies that the progress remained slow so long as the environmental conditions were placid but became accelerated with the advent of more turbulent conditions in our national life. If we have to live and keep pace with the changes in our environment, the tempo of scientific research and development must increase many-fold. The recent appointment of a Minister for Planning in the Union Government and of a statutory Planning Commission indicate that a scientific approach is being made for the solution of the major economic and social problems of the country.

The second great event of the year is the renewal of the grant of Rs.3,36,000 by Messrs. Imperial Chemical Industries (India) Limited for the award of Research Fellowships in Physics, Chemistry and Biology for the next five years. The Institute is happy that the authorities of the Imperial Chemical Industries (India) Limited approved of the way in which the previous grant of a similar amount given in 1945 was administered by the Institute and were satisfied with the scientific researches that have been carried out under the scheme. We are grateful to Messrs. Imperial Chemical Industries (India) Limited, particularly to its Chairman, Lord McGovan, for this magnificent gesture of good-will towards India and for the encouragement they have thus given to scientific research in the country. Is it too much to hope that the industrial magnates of the country will also come forward with similar grants and thereby help the Government and the country in increasing the speed of scientific research so vital for the welfare and prosperity of the masses.

The third great event of the year is our own building in which we are meeting today. This Institute was established at Calcutta in 1935, but on its recognition as the premier scientific body in the country, its headquarters were shifted to Delhi in order that Government may be able to draw on its advice expeditiously and by personal discussions. Though we have not come of age yet, we have established a small home for ourselves. We are grateful to the Government of India for the gift of the land and for funds for the building. This is only a part of our Building Project and we hope before long to get sufficient funds to complete it.

Since the transfer of the Institute to Delhi in 1945, the University of Delhi very kindly and generously provided us with accommodation at considerable inconvenience to themselves. We offer to the authorities of the University our grateful thanks for their kindness and courtesy. We hope to maintain a very close liaison with Universities in the country, for we can be complimentary to each other in the service to the nation.

Since a Committee of the Indian Science Congress recommended the establishment of the Institute, it was befitting that the first two meetings held in the Building were those of the Finance Committee and the Executive Committee of the Indian Science Congress Association.

With a building of our own, with enough encouragement and financial facilities from the Government and with the recognition of our work abroad, our duties and responsibilities have also increased, and, I think, it is time for stock-taking so that we can be fully prepared to play the rôle that may be assigned to us in the planning of future scientific development and research in the country. Having been actively associated with the working of the Institute since its inception as Treasurer, Secretary, Editor of Publications and now its President, perhaps I am in a somewhat better position to undertake such a stock-taking. We have no doubt solid achievements to our credit but at the same time there are glaring deficiencies which must be rectified before we can be above reproach. We can begin this stock-taking by reviewing our achievements in the light of the Aims and Objects for which the Institute was founded.

The Objects of the National Institute of Sciences of India are:—

(*a*) The promotion of natural knowledge in India including its practical application to problems of national welfare.

(*b*) To effect co-ordination between scientific academies, societies, institutions, and Government scientific departments and services.

(*c*) To act as a body of scientists of eminence for the promotion and safeguarding of the interests of scientists in India; and to represent internationally the scientific work of India.

(*d*) To act through properly constituted National Committees in which other learned academies and societies will be associated, as the National Research Council of India, for undertaking such scientific work of national and international importance as the Council may be called upon to perform by the public and by Government.

(*e*) To publish such proceedings, journals, memoirs and transactions, and other publications, as may be found desirable.

(*f*) To promote and maintain a liaison between Science and Letters.

(*g*) To secure and manage funds and endowments for the promotion of Science.

(*h*) To do and perform all other acts, matters, and things that may assist in, conduce to, or be necessary for the fulfilment of the above-mentioned aims and objects of the Institute.

Of all these functions, the only one that we have discharged effectively and perhaps efficiently, is regarding the publications of the Institute which have appeared more or less regularly. We have discharged our duties in this respect without favour or fear and have weathered many storms. We are specially proud of our Symposia which attract great attention abroad and give an up-to-date review of the problem discussed. We are going to make a special feature of these symposia by publishing them as Bulletins of the Institute. We have also undertaken the publication of the Progress of Science in India from 1938 to 1950 and thereafter year after year. We have suspended the publication of '*Indian Science Abstracts*' as they seemed to serve no useful purpose. Our publications and the holding of Symposia have, in my judgment, been instrumental in 'the promotion of natural knowledge in India including its practical application to problems of national welfare'.

A 'Popularisation of Science Fund' was started in 1947 with donations amounting to Rs.4,402 and a number of Nature Study paintings at a cost of Rs.4,000 were made for educational purposes but somehow the Institute has not yet been able to chalk out a definite programme. Our building is very favourably situated to cater for both New Delhi and Delhi and the Institute will give thought to organise public lectures, small exhibitions, etc. to popularise science. We hope to get considerable assistance in any such projects from the U.N.E.S.C.O. Science Co-operation Office for South Asia at Delhi.

The main object of founding the National Institute was 'to effect co-ordination between scientific academies, societies, institutions, and Government scientific departments and services', but I am afraid our achievements in this direction have been limited. The Indian Academy of Sciences at Bangalore has refused for the last several years to send their representatives on our Council, though we have shown to the Fellows of that Academy all considerations which we give to the Fellows and Members of other co-operating academies. Further, we have assisted them in getting large grants from the Central Government. Even in the case of other co-operating academies, such as the Asiatic Society, the Indian Science Congress Association and the National Academy of Sciences, we have given them representation on our Council but ourselves have no representatives on their Councils or Executive Committees. There should be a reciprocity of such representations for ensuring co-ordination.

We have received the co-operation of all learned scientific societies. The Institute has also been assisting them by awarding grants or recommending them for Government grants in aid of their respective publications. Rules have recently

been framed for the affiliation of societies of an all-India nature to the National Institute thus ensuring closer co-ordination. As regards scientific institutions, a provision is being made by the Union Government in their respective constitutions to include a representative of the National Institute of Sciences of India on their governing bodies. For example, the Institute is now represented on the Court and Council of the Indian Institute of Science, Bangalore, on the Council of the Indian Association for the Cultivation of Science, and on the General Council and Chemical Division of the Indian Standards Institution.

As regards effecting any co-ordination between the Government scientific departments and services on the one hand and non-official scientists on the other, the stage has not yet reached. There is hardly any co-ordination between Government departments and services *inter se* and it will be premature to expect any real co-ordination between the official and non-official scientists just yet. Now that there is a Ministry for Scientific Research, we hope greater co-ordination will result from its activities among official scientists working under different ministries. The National Institute is, however, providing a forum where all shades of differences can be evened out and scientists of different institutions, officials and non-officials, work together to attain common objectives. Here I must mention that the Government of India, by recognising the Institute as the premier Scientific Organisation of the country and by consulting it on all important scientific matters, added to its prestige to effect co-ordination among non-official organisations, and our efforts should first be directed to effect co-ordination among such bodies.

We have yet to take any adequate steps for the promotion and maintenance of a liaison between Science and Letters, except that the Asiatic Society is one of our co-operating academies. By holding the Symposium on the 'History of Science in South Asia', in collaboration with the U.N.E.S.C.O. Science Co-operation Office for South Asia at Delhi, we have shown our desire to promote and maintain such liaison. This Symposium, held in November last year, was attended by eminent historians and scientists and both sides seemed to have gained much by contacts. Organisations of similar Symposia will be of special value for broadening the outlook of scientists and of men of letters.

The proposal to recognise the National Institute as the Adhering Body for the International Council of Scientific Unions is still under the consideration of the Ministry of Natural Resources and Scientific Research. National Committees for collaboration with the Unions have not yet been formed though the Council of the Institute has urged on Government the necessity of doing so. It is, however, hoped that some tangible steps will be taken during the course of the next year. In view of the above position, we have not yet been able to fulfil the aims of our Object (*d*) of the Constitution.

I do not think that the Council has ever given thought to the fact that as a body of scientists of eminence, it is one of our objects to promote and safeguard the interests of scientists in India. So long as planning of research in India continues to be tactical rather than strategic, there is great need to safeguard the interests of true scientists in this country. Already, since the war, demand for scientists in high positions has upset the balance of scientific teaching and research in the country. Some of our eminent teachers and research workers are now administrators, with the result that standards have gone down in a number of universities and scientific institutions. We are now on paper producing a large number of scientists but I doubt if quality has been maintained. With the creation of new jobs, production of overnight specialists is now a common-place thing. In fact, in spite of a large number of scientific institutions in the country, I feel the scientific atmosphere is lacking. 'After all it is not so much the administrative organisation of science, but the atmosphere in which scientific work is carried out, which really matters and so long as the scientist is in control of the conditions under which he and his staff work we may be quite sure that the maintenance of the right atmosphere will be

assured' (Sir Edward Appleton at the British Commonwealth Scientific Conference held in London in 1946). As a biologist, it seems to me odd that we seek a rapid progress of science along certain lines without first creating the atmosphere in which real science can flourish. It has been overlooked that the most essential object in any scheme of scientific development must be the 'Scientist' himself and if he is deficient in certain essential qualities or lacks necessary facilities, the entire superstructure becomes fruitless. Under these circumstances, in the interest of science and of our country, it seems that we should regard 'the promotion and safeguarding of the interests of scientists of India' as one of our most important functions. In collaboration with the Ministry of Scientific Research, we can undertake this task most effectively, but I wish to avail myself of this opportunity to explore what needs be done.

One can sometimes read future events by a close study of those that happened in the past. I cannot say when the next step in the onward march of science will be taken, but it would seem that such a step will be the formation of a National Research Council under the new Ministry to co-ordinate all fundamental scientific research in the country and to ensure balanced development of all sciences. At present there is an undue emphasis on theoretical physics and problems of chemical kinetics or structures and a great neglect of biological sciences, which can play a very great part in national welfare. There is also a great need for the realisation that an indigenous technology making use of the principles of science against the background of local, social and economic structure can be far more effective in solving India's problems than the transplantation of the technology of the West. My personal experience of fishery problems has convinced me that future development can only be based on indigenous knowledge and practices and then expanding the same through scientific understanding. The possibilities of such an expansion are unlimited, provided the foundation is sound and well laid. We have much to learn from the eastern countries, particularly from China and Japan, and have, in my judgment, already wasted much time, energy and funds in copying the West.

The creation of a number of high salaried administrative jobs in Governmental services and depletion of Universities and scientific institutions has raised a problem of great national importance, and need is now felt among scientific workers for having a unified State Scientific Civil Service so that the scientists can carry on their researches uninterruptedly. Sooner or later the nation will have to consider whether the existing conditions of service for scientific workers are commensurate or even adequate for the initial training they have to undergo as compared with the administrative services. Unless the best scientific men, while carrying out scientific researches, have equal prospects of pay and promotion, it will be difficult to secure men of more than usual ability for purely scientific jobs. Further, there is a necessity for providing rapid advancement for outstanding men, and the Finance Ministry must recognise the necessity of creating additional posts for outstanding men. There is also need for the provision for the promotion of individual research workers of exceptional abilities, without necessarily expecting them to carry administrative responsibility. The appointment of Dr. C. V. Raman as National Professor and of Professor K. N. Bahl as Research Professor by the University of Lucknow are steps in the right direction. As President of the Institute, it has pained me to learn of the exodus of some of our young brilliant scientists to the U.S.A. or U.K. for lack of adequate facilities to work in India. Any national plan that leaves the man of science in a position inferior to that of his administrative or executive colleague is not going to be helpful in the least in creating a proper scientific atmosphere in the country.

From the above review of current and future events, I hope I have made it clear where our deficiencies lie and how best we can fulfil our objects. We are very favourably placed to advise the nation on planning for scientific research and development. Let us do our task fearlessly and boldly according to the best of our judgment.

Before I conclude, it is my very pleasant duty to record the thanks of the Institute and my personal thanks to the office bearers of the Institute, particularly the Secretaries, for the selfless service they have rendered during the year. I have received co-operation of the Council and of the general body of Fellows in the discharge of my duties and for this I am much obliged to each Fellow of the Institute.

S. L. HORA.

New Delhi,
5th October, 1951

ANNUAL REPORT, 1950-51

The Council of the National Institute of Sciences of India have the pleasure in submitting the following report on the general concerns of the Institute for the year 1950-51, under provisions of Rule 43(*f*).

Membership.

Out of the 256 Ordinary Fellows at the close of the year 1949-50, three died, one resigned (Dr. Nazir Ahmad) and the names of five (Mr. W. C. Ash, Dr. J. C. Bardhan, Dr. M. N. De, Mr. J. R. Haddow and Prof. P. S. Macmahon) were removed from the list under Rule 31. Fifteen new Ordinary Fellows were elected, but the election of one became null and void under Rule 9. At the close of the year the number of Ordinary Fellows stood at 261 (Appendix I).

In addition to 29 Honorary Fellows listed in Appendix I, the following four were elected during the year:—

Sir Alexander Fleming, Kt., F.R.C.S., M.D., F.R.S., N.L., The Wright-Fleming Institute of Microbiology, St. Mary's Hospital Medical School, Paddington, London, W. 2.

Prof. Richard Kühn, N.L., Director, Max Planck-Institut fur Forschung Institut fur Chemie, Heidelberg, Germany.

Prof. H. J. Muller, D.Sc., N.L., Professor of Zoology, Indiana University, Bloomington, Indiana, U.S.A.

Prof. Selman A. Waksman, Professor of Microbiology, New Jersey Agricultural Experimental Station, Nicol Avenue, New Brunswick, New Jersey, U.S.A.

Steps have been taken to confer on them the Honorary Fellowship of the Institute through diplomatic channels.

Obituaries.

The death of the following Fellows is noted with regret:—

Mr. T. P. Bhaskara Shastri, Foundation Fellow.
Prof. K. C. Mehta, Foundation Fellow.
Prof. P. Neogi, Ordinary Fellow.
Prof. E. S. Goodrich, Honorary Fellow.

The Institute also adopted a vote of condolence on the death of Prof. Harold Bohr.

Meetings.

The Sixteenth Annual General Meeting was held at headquarters of the Institute, Delhi University, Delhi, on the 6th October, 1950, and the Anniversary General Meeting at Bangalore on the 1st January, 1951, under the Presidentship of Prof. S. N. Bose. Three Ordinary General Meetings were also held. At all these meetings many papers were read and discussed, and the following symposia were also held:—

May 5, 1950 (Delhi) .. Dyestuff Industries in India—organized by Prof. B. B. Dey.

August 4-5, 1950 (Calcutta)	..	Multipurpose River Projects in India's National Economy—organized by Dr. B. C. Guha, Dr. S. L. Hora and Dr. W. D. West.

The following films were also shown on this occasion:—(1) Tennessee Valley Authority. (2) Malaria Control in the Tennessee Valley.

October 6, 1950 (Delhi)	..	Scientific Utilization of Indian Coals—organized by Dr. D. N. Wadia.
January 1, 1951 (Bangalore)	..	Organic *vs.* Inorganic Manures—organized by Prof. N. R. Dhar.

At the Ordinary General Meeting held on the 7th April, 1950, Prof. P. M. S. Blackett, N.L., of the University of Manchester, delivered a lecture on 'A New Type of Meson'.

A symposium on the 'History of Science in South Asia' was held in collaboration with the U.N.E.S.C.O. Science Co-operation office for South Asia on November 5–7, 1951, and was participated by well-known historians and scientists. It was attended by delegates from various scientific societies of India and also from Thailand and Indonesia.

In addition, Prof. George B. Creasey, Chairman, International Geographical Union, gave a talk on 'Land-Use Possibilities in Asia' on the 11th January, 1951. A reception was held on the 29th January, 1951, to meet Sir Lewis Fermor, first President of the Institute, who came to India in connection with the Centenary Celebrations of the Geological Survey of India.

The Council.

At the Sixteenth Anniversary General Meeting held on the 1st January, 1951, the office bearers and members of Council for 1951 were elected. Together with the representatives nominated by the co-operating Academies, the Indian Science Congress Association and the Government of India, the Council for 1951 was constituted as follows:—

President	..	Dr. S. L. Hora (Calcutta).
Vice-Presidents	..	Dr. K. S. Krishnan (Delhi).
		Prof. P. Parija (Banaras).
Additional Vice-Presidents	..	Prof. K. N. Bagchi (Calcutta).
		Prof. N. R. Dhar (Allahabad).
		Prof. P. C. Mahalanobis (Calcutta).
		Representative of the Indian Academy of Sciences (nomination not received).
Treasurer	..	Dr. C. G. Pandit (Delhi).
Foreign Secretary	..	Dr. J. N. Mukherjee (Roorkee).
Secretaries	..	Prof. D. S. Kothari (Delhi).
		Dr. H. S. Pruthi (Delhi).
Editor of Publications	..	Prof. J. M. Sen (Calcutta).
Members	..	Dr. S. P. Agharkar (Poona).
		Prof. K. N. Bahl (Lucknow).
		Dr. S. K. Banerji (Calcutta).
		Prof. H. J. Bhabha (Bombay).
		Prof. S. Bhagavantam (Hyderabad).
		Prof. B. B. Dey (Madras).
		Dr. B.C. Guha (Calcutta).
		Prof. A. C. Joshi (Hoshiarpur).
		Prof. R. C. Majumdar (Delhi).
		Dr. B. P. Pal (Delhi).
		Dr. V. G. Panse (Indore).
		Dr. Mata Prasad (Bombay).
		Dr. L. A. Ramdas (Poona).
		Prof. M. N. Saha (Calcutta).
		Prof. N. R. Sen (Calcutta).
		Dr. P. V. Sukhatme (Delhi).
		Dr. A. C. Ukil (Calcutta).

Ex-officio Members (Past Presidents)	..	Dr. S. S. Bhatnagar (1947 and 1948) (Delhi). Prof. S. N. Bose (1949 and 1950) (Calcutta). Dr. R. N. Chopra (1939 and 1940) (Jammu). Dr. J. C. Ghosh (1943 and 1944) (Kharagpur). Dr. Baini Prashad (1941 and 1942) (Calcutta). Dr. D. N. Wadia (1945 and 1946) (Delhi).
Additional Members	..	Dr. J. L. Bhaduri (Calcutta). Dr. B. Mukerji (Lucknow). Dr. P. L. Srivastava (Allahabad). Representative of the Indian Academy of Sciences (nomination not received).
Representative of Government of India		Dr. C. G. Pandit.

The Sectional and other Committees appointed by the Council are shown in Appendix II. The Council held five meetings. Some important resolutions passed by the Council are given in Appendix III.

Representations on Scientific Bodies.

Dr. S. L. Hora and Prof. B. B. Dey were nominated for the year ending 31st March, 1952, as representatives of the Institute on the Council of the Indian Association for the Cultivation of Science.

The representatives on the Indian Standards Institution were as follows:—

General Council	.. ..	Mr. G. R. Paranjpe.
Chemical Division	.. ..	Dr. B. Mukerji (principal) and Prof. K. N. Bagchi (alternative).
Weights and Measures Committee	..	Prof. S. K. Mitra (principal) and Mr. G. C. Mitter (alternative).

Prof. A. C. Banerji and Dr. B. Mukerji were appointed to represent the Institute at the Annual Meeting of the British Association for the Advancement of Science at Birmingham in August-September 1950.

The National Institute has continued to act as adviser to the Department of Scientific Research (now the Ministry of Natural Resources and Scientific Research) in all matters concerning the International Scientific Unions and their co-ordinating body—I.C.S.U. The proposal to recognize the National Institute of Sciences of India as the Adhering Body for the I.C.S.U. is still under the consideration of the Ministry. National Committees for collaboration with the Unions have not yet been formed, but it is hoped that some tangible steps will be taken, during the course of next year. The Council of the Institute has already urged on Government the necessity for doing so.

With the growth of science and technology in Asia and the Far East, it is most desirable that scientists in these countries participate more fully in international scientific activities. A development of interest to international co-operation in science is the growing number of international scientific and technological conferences which are being held in Asia and the Far East during recent years. A list of these are given below :—

*(1) International Anti-Locust Conference. (New Delhi, 1950)	Invited by Govt. of India and organized by National Committee of World Power Conferences and Central Board of Irrigation.
*(2) International Conference on Hydraulic Structures Research. (New Delhi, 1951)	
*(3) Fourth Congress on Large Dams. (New Delhi, 1951)	
*(4) Meetings of two Sectional Committees of World Power Conference, *viz.*, (i) Use of Electricity in Agriculture. (ii) Co-ordination of the Development of Industries and Power Resources. (New Delhi, 1951)	
(5) International Commission on Irrigation and Drainage. (Mysore, 1951)	

* Information supplied by the Ministry of Natural Resources and Scientific Research, Govt. of India, New Delhi.

(6) E.C.A.F.E.-U.N.E.S.C.O. Working Party on the availability of Educational and Scientific Materials. (New Delhi, 1950; Bangkok, 1951)	Sponsored by E.C.A.F.E.
(7) Flood Control Conference. (New Delhi, 1951)	
(8) Forestry and Timber Utilization. (Bangalore, 1949)	
(9) Livestock Improvement. (Lucknow, 1950)	Sponsored by F.A.O.
(10) Rice Commission. (Rangoon, 1950; Bogor, 1951)	
(11) Nutrition Commission. (Rangoon, 1950)	
(12) Symposium on Fundamental Particles. (Bombay, 1951)	Sponsored by I.U.P.A.P. in collaboration with the Tata Institute of Fundamental Research.
(13) Symposium on History of Science in South Asia... (Delhi, 1950)	Sponsored by the National Institute of Sciences of India in collaboration with the U.N.E.S.-C.O.
(14) Symposium on Origin and Distribution of Cultivated Plants in South Asia. (New Delhi, 1951)	Sponsored by U.N.E.S.-C.O. in collaboration with the Indian Society of Genetics and Plant Breeding.

Another matter of great interest to scientists in India and elsewhere is the inauguration in January, 1951, of the Pan Indian Ocean Science Association in Bangalore under the auspices of the Indian Science Congress Association, for which our thanks are due to our Australian colleagues who took the initiative. The independent countries around the Indian Ocean and countries having territories bordering the Indian Ocean are eligible for membership of the P.I.O.S.A. The developments are very welcome as they are most helpful for the development of the progress of science and the improvement of the conditions of the people in the countries concerned.

Institute Building.

Good deal of progress has been made in the construction of the building. Electrification and plumbing have been entrusted to contractors by the Architect. The building is likely to be ready for occupation before the end of September, 1951.

Delegations to International Conferences.

Fellows of the Institute represented the Government of India at various International Conferences during the year under report:—

1. International Rice Commission of the F.A.O.—(1) Rice Breeders Working Party, and (2) Working Party on Fertilizers and Manures, April 1950 (Bogor, Indonesia) —Mr. K. Ramiah.
2. Tenth Meeting of the International Union of Biological Sciences, July 1950 (Stockholm)—Prof. P. Maheshwari and Prof. F. R. Bharucha.
3. Seventh International Botanical Congress, July 1950 (Stockholm)—Prof. P. Maheshwari and Prof. F. R. Bharucha.
4. International Physiological Congress, August 1950 (Copenhagen)—Dr. B. Mukerji.
5. Meeting of the Executive Board of the International Council of Scientific Unions, August 1950 (Berne)—Dr. J. N. Mukherjee.
6. International Congress of Mathematicians, August-September 1950 (Cambridge, Mass, U.S.A.)—Prof. P. C. Mahalanobis, Prof. S. Chowla, Prof. R. C. Bose, Mr. S. N. Roy.
7. Meeting of the Associations for the Advancement of Science held under the auspices of the U.N.E.S.C.O., September 1950 (Paris)—Dr. B. Mukerji.
8. Third Session of the Indo-Pacific Fisheries Council, January-February 1951 (Madras) —Dr. S. L. Hora, Dr. S. B. Setna and Dr. B. N. Chopra.
9. Conference of International Locust Experts, March 1951 (Cairo)—Dr. H. S. Pruthi.
10. Extraordinary Conference of Directors of the International Meteorological Organization, March 1951 (Paris)—Mr. V. V. Sohoni and Mr. S. Basu.
11. First Congress of the World Meteorological Organization, March-April 1951 (Paris) Mr. V. V. Sohoni and Mr. S. Basu.

Prof. A. C. Banerji was sent on deputation by the Government of India to visit observatories and universities in Europe and America from 6th February to 8th September, 1950. Dr. L. C. Verman represented Indian Body on the following International Conferences:—

1. I.S.O. Technical Committee on Raw Materials for paints, varnishes and similar products, 1950 (Zurich).
2. I.S.O. Council and Council Committee on Modification of Statutes, July 1950 (Geneva).
3. International Electrotechnical Commission Technical Committees, July 1950 (Paris).

Dr. N. K. Bose attended the International Engineering Conference at Bombay and Delhi as a representative of the Government of West Bengal.

Publications.

Six numbers of *Proceedings*, Vol. XVI, Nos. 2-6 and Vol. XVII, No. 1, about 606 pages, were published during the year.

Library.

About 400 books and pamphlets were added during the year. About ten new institutions were added to the list for exchange of their publications with those of the Institute, which include:—

1. Sarawak Museum and Library.
2. Kyushu University Library.
3. College of Agriculture, Kyoto, Japan.
4. Textile Institute, Manchester.
5. Missouri Botanical Garden.

A list of periodicals received is given in Appendix IV.

Presentation.

Dr. E. U. Condon, Director, Bureau of Standards, Washington, has presented the following films to the Institute:—

1. Explosions on the Sun.
2. Low Temperature.
3. Ionosphere Storm on March 15-16, 1948.

Dr. Hansraj Gupta has presented to the Library original of his work on 'Three Square Table'.

Several presents were received in the Library. Particular mentions are made of the 59 volumes of 'Fauna of British India' series from the National Archives and the Svedberg from Uppsala University.

Grants-in-aid of Publications.

During the year under report Publication Grant of Rs.15,000 was distributed as follows:—

	Rs.
National Academy of Sciences, India	1,000
Indian Science Congress Association	1,000
Current Science Association	1,000
Indian Science News Association	1,000
Indian Mathematical Society	500
Calcutta Mathematical Society	500
Bharata Ganita Parishad	300
Indian Society of Agricultural Statistics	500
Indian Physical Society	800

	Rs.
Indian Chemical Society	500
Institution of Chemists (India)	600
Society of Biological Chemists, India	500
Indian Geographical Society	500
Calcutta Geographical Society	500
Geological, Mining and Metallurgical Society of India	500
National Geographical Society of India	500
Indian Botanical Society	700
Indian Society of Genetics and Plant Breeding	250
Indian Phytopathological Society	250
Zoological Society of India	,000
Entomological Society of India	800
Indian Anthropological Institute	200
Indian Pharmaceutical Association	500
Indian Institute for Medical Research	400
Physiological Society of India	250
Indian Psychological Association	200
Indian Dairy Science Association	250

Grants-in-aid to Learned Societies from the Central Government.

From among the societies which approached the Institute for obtaining grants-in-aid from the Government Funds, the following were recommended during the year:—

For the year 1950-51.

(*a*) Current Science Association—A non-recurring grant of Rs.1,000 in support of its Journal.
(*b*) Indian Chemical Society—Normal recurring grant of Rs.3,000.
(*c*) Institution of Chemists (India)—Normal recurring grant of Rs.1,000.
(*d*) Calcutta Mathematical Society—A recurring grant of Rs.1,000.

In addition to the above the following grants which could not be made available during the year 1949-50 were also recommended:—

(*a*) Indian Science News Association—A token grant of Rs.5,000 during 1950-51 and Rs.20,000 during 1951-52 for a Hindi edition of 'Science and Culture'.
(*b*) Indian Institute of Metals—Rs.1,000 in support of its Transactions.
(*c*) Zoological Society of India—Rs.1,000 in support of its Journal.
(*d*) Entomological Society of India—Rs.1,000 to bring the publication of its Journal up to date.
(*e*) Mining, Geological and Metallurgical Institute of India—Rs.3,000 to bring arrears of publications up to date.
(*f*) Physiological Society of India—Rs.1,000 in support of its Journal.

For the year 1951-52.

For considerations of economy the Council restricted themselves to recommending the following grants for 1951–52 in addition to those falling due as recurring:—

(*a*) Indian Science Congress Association—a recurring grant of Rs.25,000 for its publications.
(*b*) Zoological Society of India—a non-recurring grant of Rs.1,500 for its Journal.
(*c*) Entomological Society of India—a non-recurring grant of Rs.1,500 for its Journal.

National Institute of Sciences Research Fellowships.

Senior Research Fellowships.

The following Senior Research Fellows were at work at places mentioned against their names:—

1. Mr. S. P. Basu (Zoology), All-India Institute of Hygiene and Public Health, Calcutta.
2. Dr. J. Bhimasenachar (Physics), Andhra University Waltair (up to 15th June, 1950).
3. Mr. U. R. Burman (Mathematics), Calcutta University (up to 15th April, 1950).

4. Dr. A. B. Kar (Physiology), Central Drugs Laboratory, Calcutta.
5. Dr. P. B. Mathur (Botany), Banaras Hindu University (from 1st June to 31st August, 1950).
6. Dr. P. C. Mukherji (Chemistry), Calcutta University (up to 9th December, 1950).
7. Dr. L. S. Ramaswami (Zoology), Central College, Bangalore.
8. Dr. A. N. Roy (Chemistry), Bengal Engineering College, Sibpur.
9. Dr. K. V. Srinath (Botany), Central College, Bangalore (up to 28th February, 1951).
10. Dr. Sukh Dev (Chemistry), Indian Institute of Science, Bangalore.
11. Mr. V. R. Thiruvenkatachar (Mathematics), Central College, Bangalore.

Junior Research Fellowships.

The following Junior Research Fellows were at work at places mentioned against their names:—

1. Mr. B. K. Banerjea (Physics), Calcutta University.
2. Dr. P. M. Bhargava (Chemistry), Laboratories of Scientific and Industrial Research, Hyderabad.
3. Mr. V. Chandrasekharan (Physics), Indian Institute of Science, Bangalore.
4. Mr. A. K. Chaudhuri (Physics), Calcutta University.
5. Dr. K. Das Gupta (Physics), Calcutta University (up to 17th November, 1950).
6. Mr. S. Dutta Majumdar (Physics), Calcutta University.
7. Dr. G. S. Deshmukh (Chemistry), Banaras Hindu University.
8. Dr. S. G. Joshi (Chemistry), Maharashtra Association for the Cultivation of Science, Poona.
9. Mr. S. D. Misra (Zoology), Lucknow University.
10. Mr. D. K. Mukherji (Botany), Indian Agricultural Research Institute, New Delhi (up to 7th November, 1950).
11. Dr. (Mrs.) Vidyavati Paul (Zoology), Delhi University.
12. Mr. Y. Sundar Rao (Botany), Government College, Hoshiarpur (up to 17th October, 1950).
13. Mr. N. Sathapathy (Geology), Andhra University, Waltair.
14. Mrs. Ira Sarkar (Zoology), Calcutta University.
15. Mr. K. Subramanyam (Botany), Central College, Bangalore.
16. Mr. B. V. Sukhatme (Mathematics), Indian Council of Agricultural Research (up to 28th September, 1950).
17. Mr. S. Vedaraman (Chemistry), Indian Institute of Science, Bangalore (up to 31st August, 1950).

Imperial Chemical Industries (India) Research Fellowships.

The following I.C.I. (India) Research Fellows were at work at places mentioned against their names:—

1. Mr. C. Balakrishnan (Physics), National Physical Laboratory, New Delhi.
2. Mr. S. P. Basu (Zoology), Zoological Survey of India, Calcutta (up to 15th July, 1950).
3. Mr. H. N. Bose (Physics), Calcutta University (up to 30th June, 1950).
4. Dr. I. M. Chak (Chemistry), Central Drug Research Institute, Lucknow.
5. Dr. A. K. Chakrabarti (Botany), Calcutta University.
6. Mr. T. V. Desikachari (Botany), Madras University.
7. Dr. S. N. Ghosh (Physics), Calcutta University (up to 22nd August, 1950).
8. Mr. A. G. K. Menon (Zoology), Zoological Survey of India, Calcutta.
9. Dr. G. C. Mitra (Botany), Calcutta University.
10. Mr. J. Mitra (Botany), Calcutta University.
11. Mr. T. V. R. Pillay (Zoology), Zoological Survey of India, Calcutta.
12. Dr. L. Ramachandra Rao (Chemistry), Andhra University (up to 31st January, 1951).
13. Dr. C. Ramasastry (Physics), Andhra University.
14. Dr. K. K. Reddi (Chemistry), Indian Institute of Science, Bangalore (up to November, 1950).
15. Dr. P. K. Sen Chaudhury (Physics), Bose Institute, Calcutta.
16. Dr. C. V. Subramanian (Botany), Madras University (up to 13th June, 1950).

Summaries of Annual and Final Reports of Research Fellows are given in Appendix VII.

The term of the original endowment of the Imperial Chemical Industries (India) Research Fellowship having expired, the Council approached the Imperial Chemical Industries, Ltd., to extend the scheme. The Imperial Chemical Industries, Ltd., have been pleased to sanction a second scheme for the award of Research Fellowships on the same terms and conditions as before. The first batch of Research Fellows under this scheme will be appointed during the year 1951-52.

A National Research Fellowship has been awarded to Dr. M. O. P. Iyengar for a period of two years for the preparation of a monograph on Algae.

Financial.

The recurring grant-in-aid towards expenditure on salaries of staff, research fellowships, travelling, library and publications amounted to Rs.2,00,000 during the financial year 1950-51. The Calcutta University, as in previous years, donated a sum of Rs.500 in aid of the Institute and Rs.600 were received from Osmania University.

The audited accounts for the financial year ending 31st March, 1951, are given in Appendix V, in which are also given subsidiary statements relating to the I.C.I. Research Fellowships grant, Chandrakala Hora Memorial Medal Endowment, the grant for compilation of a National Register of Scientific and Technical Personnel and the Popularization of Science Fund.

The Budget Estimates for 1951-52 are shown in Appendix VI.

Post of Assistant Secretary.

In October, 1950, on the expiry of the term as Officer Supervisor of Mr. A. M. Desai, it was decided to take steps to appoint an Assistant Secretary. The post of Assistant Secretary had been in abeyance for a period of nearly two and a half years. For this period as an interim measure Mr. Desai was appointed as Officer Supervisor. The post has been advertised and it is expected that the appointment will be made some time before the end of 1951.

The Council placed on record the appreciation of Mr. Desai's services to the Institute.

APPENDIX I

LIST OF FELLOWS

ORDINARY FELLOWS

1. ABRAHAM, W. E. V., Lt.-Col., A.R.C.S. (I.), F.G.S., M.Inst.P.T., Managing Director, Burmah Oil Co., Ltd., Britannic House, Finsbury Circus, London, E.C. 2. (1936).
2. AGHARKAR, S. P., M.A., Ph.D., F.L.S., Head of the Dept. of Botany, Maharashtra Association for the Cultivation of Science, Law College, Poona 4.
3. AHMAD, BASHIR, M.Sc., Ph.D., Director, Institute of Chemistry, Punjab University, The Mall, Lahore. (1944).
4. AIYAR, R. GOPALA, M.A., L.T., M.Sc., Professor of Zoology, Andhra University, Waltair. (1938).
5. AJREKAR, S. L., B.A. (Cantab.), Dip. Agric., I.E.S. (Retired), 855 Shivajinagar, Bhandarkar Institute Road, Poona 4.
6. ANANDA RAU, K., Rao Bahadur, M.A., I.E.S. (retd.), 29, Boag Road, Thyagarayanagar, Madras.
7. ANTIA, D. P., D.Sc., Metals Development Officer, Ministry of Industry and Supply, Government of India; Chawdhury Building, Block 'K', Connaught Circus, New Delhi. (1950).
8. ASUNDI, R. K., M.Sc., Ph.D. (Cantab.), Professor of Physics, Banaras Hindu University, Banaras. (1951).
9. AUDEN, J. B., M.A., Sc.D. (Cantab.), F.A.S., Superintending Geologist, Geological Survey of India, 27 Chowringhee Road, Calcutta. (1938).
10. AULUCK, F. C., Ph.D., D.Sc., Reader in Physics, Delhi University, Delhi. (1950).
11. AWATI, P. R., B.A. (Cantab.), D.I.C., I.E.S. (Retd.), 47/5 Prabhat Road, Poona 4.
12. BAGCHEE, K. D., D.Sc., D.I.C., Forest Botanist, Forest Research Institute, New Forest, Dehra Dun.
13. BAGCHI, K. N., Rai Bahadur, B.Sc., M.B., D.T.M., F.R.I.C., 5 Ballygunge Place, Ballygunge, Calcutta 19. (1940).
14. BAHL, K. N., D.Sc., D.Phil., F.A.S., Vice-Chancellor Patna University, Patna.
15. BANERJEE, K., D.Sc., Mahendralal Sircar Professor of Physics, Indian Association for the Cultivation of Science, Jadavpur, Calcutta 32. (1939).
16. BANERJI, A. C., M.Sc., M.A., F.R.A.S., I.E.S., Professor of Mathematics, Allahabad University; Gyan Kutir, Beli Road, Allahabad.
17. BANERJI, I., D.Sc., F.L.S., Lecturer in Botany, Calcutta University, 35 Ballygunge Circular Road, Calcutta 19. (1945).
18. BANERJI, S. K., O.B.E., D.Sc., F.R.M.S., Director-General of Observatories, India Meteorological Department (retd.); 3 Ramani Chatterjee Road, R. B. Avenue P.O., Calcutta 29.
19. BASU, J. K., M.Sc., Ph.D. (Lond.), Soil Physicist to the Government of Bombay, Central Buildings, Poona. (1941).
20. BASU, K. P., D.Sc., (Dacca), Ph.D. (Munich), Head of the Dairy Chemistry Section, Indian Dairy Research Institute, Hosur Road, Bangalore 1. (1951).
21. BASU, N. M., M.A., 63 Hindusthan Park, Ballygunge, Calcutta. (1944).
22. BASU, S., M.Sc., Dy. Director-General of Observatories, Meteorological Office, Ganeshkhind Road, Poona 5. (1946).
23. BASU, U. P., D.Sc., Director, Bengal Immunity Research Institute; 98/4 Surendranath Banerjea Road, Calcutta 14. (1946).
24. BEHARI, RAM, M.A., Ph.D., Sc.D., Professor of Mathematics, Delhi University, Delhi. (1941).
25. BHABHA, H. J., Ph.D., D.Sc. F.R.S., Director, Tata Institute of Fundamental Research, Apollo Pier Road, Bombay. (1941).

26. Bhaduri, J. L., D.Sc. (Edin.), F.Z.S.I., F.A.S., Lecturer in Zoology, Calcutta University, 35 Ballygunge Circular Road, Calcutta 19. (1949).

27. Bhaduri, P. N., Ph.D., F.R.M.S., F.R.H.S., F.L.S., Assistant Cytogeneticist, Indian Agricultural Research Institute, Pusa Road, New Delhi. (1944).

28. Bhagavantam, S., D.Sc., Director, Physical Laboratory, Osmania University, Hyderabad, Deccan. (1949).

29. Bharadwaja, Y., M.Sc., Ph.D. (Lond.), F.L.S., Professor and Head of the Department of Botany, Banaras Hindu University, Banaras. (1937).

30. Bharucha, F. R., M.Sc., D.Sc., Professor and Head of the Department of Botany, The Institute of Science, Mayo Road, Fort, Bombay 1. (1939).

31. Bhatnagar, P. L., D.Phil., D.Sc., Head of the Department of Mathematics, St. Stephen's College, Delhi. (1950).

32. Bhatnagar, Sir S. S., Kt., O.B.E., D.Sc., F.R.S., F.R.I.C., F.Inst.P., Secretary, Ministry of Natural Resources and Scientific Research, Government of India, Central Secretariat, North Block, New Delhi.

33. Bhattacharya, D. R., Rai Bahadur, D.Sc., Ph.D., F.Z.S., Vice-Chancellor, Allahabad University; 7 Malaviya Road, Allahabad.

34. Bhimachar, B. S., D.Sc., Fishery Biologist, Central Marine Fisheries Research Station, West Hill, Calicut. (1948).

35. Biswas, K., D.Sc., F.R.S.E., Superintendent, Royal Botanic Garden, Botanic Gardens P.O., Howrah. (1950).

36. Bomford, G., Brigadier, R.E., Hainton Lodge, Sutton Courtenay, Berkshire, England. (1935).

37. Bor, N. L., C.I.E., M.A., D.Sc., F.L.S., c/o Messrs. Lloyds Bank, Ltd., 6 Pall Mall, London, S.W. 2. (1941).

38. Bose, D. M., M.A., B.Sc., Ph.D., Director, Bose Institute, 93 Upper Circular Road, Calcutta 9.

39. Bose, J. P., M.B., F.C.S., 'The Sanctuary', 41/4A Baghbazar Street, Calcutta 3. (1950).

40. Bose, N. K., M.Sc., Ph.D., Director, River Research Institute, Bengal, Anderson House, Alipur, Calcutta. (1938).

41. Bose, P. C., B.Sc. (Glas.), Deputy Director, Health Services (Engineering), Government of West Bengal; 21 Mandeville Gardens, Calcutta. (1948).

42. Bose, P. K., D.Sc., Director, Indian Lac Research Institute, Namkum, Ranchi. (1944).

43. Bose, R. C., M.A., Professor, Institute of Mathematical Statistics, University of N. Carolina, Chapel Hill, N.C., U.S.A. (1942).

44. Bose, S. N., M.Sc., Khaira Professor of Physics, Calcutta University, 92 Upper Circular Road, Calcutta 9.

45. Bose, S. R., M.A., D.Sc., F.R.S.E., Professor of Botany, R. G. Kar Medical College, 1 Belgachia Road, Calcutta. (1935).

46. Burridge, W., D.M., M.A. (Oxon.), 366 Woodstock Road, Oxford.

47. Chakrabarty, S. K., D.Sc., Head of the Department of Mathematics, Bengal Engineering College, Botanic Gardens P.O., Howrah. (1949).

48. Chakravarti, D., D.Sc., Lecturer in Chemistry, Calcutta University, 92 Upper Circular Road, Calcutta 9. (1949).

49. Chatterjee, S. C., D.Sc., Professor and Head of the Department of Geology, Science College, Patna University, Patna 5. (1948).

50. Chattopadhyay, K. P., M.Sc. (Cantab.), Professor and Head of the Department of Anthropology, University College of Science; 2 Palm Place, Ballygunge, Calcutta 19. (1951).

51. Chaudhuri, R. N., M.B., M.R.C.P. (Edin.), T.D.D. (Wales), F.S.M.F., Director, School of Tropical Medicine, Chittaranjan Avenue, Calcutta 12. (1950).

52. Chopra, B. N., D.Sc., F.L.S., Deputy Fisheries Development Adviser, Government of India, Ministry of Agriculture, New Delhi. (1935).

53. Chopra, Sir R. N., Kt., C.I.E., M.D., Sc.D., F.A.S., F.R.C.P., Brevet-Col., I.M.S. (retired), Director, Drug Research Laboratory, Jammu-Tawi, Jammu and Kashmir State.

54. Chowdhury, J. K., M.Sc., Dr.Phil. (Berlin), Head of the Department of Chemistry, Bose Institute, 93 Upper Circular Road, Calcutta 9. (1938).

55. Chowdhury, K. Ahmad, M.B.E., B.A., B.Sc., M.S., D.Sc., Wood Technologist, Forest Research Institute, New Forest, Dehra Dun. (1940).

56. CHOWLA, S., M.A., Ph.D., School of Mathematics, Institute of Advanced Study, Princeton, New Jersey (U.S.A.).
57. COATES, J., A.R.S.M., F.G.S., Eyton House, Leominster, Herefordshire, England. (1946).
58. CROOKSHANK, H., C.I.E., B.A., B.A.I., D.Sc., Geological Survey of Pakistan, Quetta. (1938).
59. DAS, A. K., D.Sc., Director, Solar Physics Observatory, Kodaikanal, S. India. (1943).
60. DAS, B. K., D.Sc. (Lond.), Professor and Head of the Department of Zoology, Osmania University; c/o Raghe Ali's House, 151 Morredpally, Secunderabad, Deccan. (1949).
61. DAS GUPTA, C. R., M.B., D.T.M. (Cal.), Head of the Department of Haematology, School of Tropical Medicine, Calcutta 12. (1951).
62. DASTUR, J. F., M.Sc., D.I.C., Scarsdale, Panday Road, Colaba, Bombay. (1948).
63. DASTUR, R. H., M.Sc., Plant Physiologist, Institute of Plant Industry, Indore.
64. DATTA, S., D.Sc., D.I.C., 39 Hindusthan Park, P.O. R.B. Avenue, Calcutta 29. (1935).
65. DATTA, S., D.Sc., F.R.S.E., M.R.C.V.S., D.T.V.M., Major, Director, Indian Veterinary Research Institute, Izatnagar, Bareilly, U.P. (1938).
66. DE, P., M.B. (Cal.), F.R.C.P.E., 172 Lansdowne Road, Calcutta 29. (1943).
67. DESAI, R. D., D.Sc. (Lond.), D.I.C., F.R.I.C., L. D. Arts College and M. G. Science Institute, Navarangpura, Ahmedabad 9. (1942).
68. DEY, B. B., D.Sc., F.R.I.C., I.E.S. (retd.), 77 High Road, Mylapore, Madras.
69. DHAR, N. R., D.Sc., F.R.I.C., I.E.S. (retd.), Professor of Chemistry, Allahabad University, Allahabad.
70. DIKSHIT, B. B., M.B.B.S. (Bombay), Ph.D. (Edin.), M.R.C.P. (Edin.), D.P.H. (Calcutta), Principal, B.J. Medical College, Poona. (1941).
71. DUTT, S. B., D.Sc., D.I.C., F.R.I.C., Professor of Chemistry, Delhi University, Delhi. (1935).
72. DUTTA, A. K., D.Sc., Mayurbhanj Professor of Physics, Utkal University, Cuttack, (1948).
73. DUTTA ROY, R. K., Dr.Ing., Chemist, Geological Survey of India, 27 Chowringhee Road, Calcutta 13. (1948).
74. ELWIN, VERRIER, M.A., D.Sc. (Oxon.), F.A.S., Taru House, P.O. Patangarh, Dt. Mandla, C.P. (1943).
75. EVANS, P., B.A., F.G.S., Chief Geologist, Burmah Oil Co., Ltd., Britannic House, Finsbury Circus, London, E.C. 2.
76. FERMOR, SIR LEWIS L., Kt., O.B.E., D.Sc., A.R.S.M., M.Inst.M.M., F.G.S., F.A.S., F.R.S., 24 Durdham Park, Bristol 6.
77. FOWLER, GILBERT J., D.Sc., F.R.I.C., Consulting Chemist, Central Hotel, Bangalore.
78. GANAPATHI, K., D.Sc., Assistant Director, Chemotherapy Department, Haffkine Institute, Parel, Bombay. (1946).
79. GANGULY, P. B., D.Sc. (Lond.), Principal, Science College, Patna. (1945).
80. GEE, E. R., M.A., F.G.S., Waveney, The Linkway, Sutton, Surrey, England. (1935).
81. GHATAGE, V. M., D.Sc., D.Phil. (Gottingen), A.F.R.Ae.S. (Lond.), M.I.Ae.Sc. (U.S.A.), Chief Designer, Hindusthan Aircraft, Ltd., Bangalore. (1950).
82. GHOSH, B. N., D.Sc. (Lond.), Reader in Physical Chemistry, University College of Science, 92 Upper Circular Road, Calcutta 9. (1942).
83. GHOSH, J., M.A., Ph.D., 9 Satyen Datta Road, Calcutta 29. (1936).
84. GHOSH, SIR J. C., Kt., D.Sc., F.A.S., Director, Indian Institute of Technology, Kharagpur, B.N.R.
85. GHOSH, P. K., M.Sc., D.I.C., D.Sc. (Lond.), Geologist, Geological Survey of India, 27 Chowringhee Road, Calcutta 13. (1941).
86. GHOSH, R. N., D.Sc., Reader in Physics, Allahabad University; 152 South Malaka, Allahabad. (1939).
87. GHOSH, SUDHAMOY, M.B.E., D.Sc. (Edin.), F.R.I.C., Emeritus Professor, School of Tropical Medicine; 15 Justice Chundermadhab Road, P.O. Elgin Road, Calcutta. (1945).
88. GHOSH, SUDDHODAN, D.Sc., Lecturer in Applied Mathematics, University College of Science, 92 Upper Circular Road, Calcutta 9. (1951).
89. GHURYE, G. S., M.A., Ph.D., Professor of Sociology, University of Bombay, Fuller Road, Bombay. (1941).
90. GILL, P. S., M.S., Ph.D. (Chicago), F.A.P.S., Professor of Physics, Muslim University, Aligarh. (1945).

91. Glennie, E. A., D.S.O., Brigadier, R.E., Steepways, Cross Oak Road, Berkhamsted, Herts, England.

92. Gravely, F. H., D.Sc., F.A.S., 95 Northcourt Avenue, Reading, England.

93. Greval, S. D. S., M.D., Ch.B., D.P.H., Lt.-Col., I.M.S. (R.), School of Tropical Medicine, Chittaranjan Avenue, Calcutta 12. (1951).

94. Guha, B. C., D.Sc., Member, Damodar Valley Corporation, Anderson House, Alipore, Calcutta 27. (1941).

95. Guha, B. S., M.A., A.M., Ph.D., F.A.S., Director, Department of Anthropology, Indian Museum, 27 Chowringhee Road, Calcutta 13.

96. Guha, P. C., D.Sc., Professor of Organic Chemistry, Indian Institute of Science, Malleswaram, Bangalore. (1935).

97. Gupta, Hansraj, Ph.D., Senior Lecturer in Mathematics, Government College, Hoshiarpur. (1950).

98. Gupta, J. C., M.B. (Cal.), 20 Brindaban Mallick Lane, Amherst Street P.O., Calcutta 9. (1945).

99. Gupta, S., M.Sc., Reader in Theoretical Physics, Muslim University, Aligarh. (1951).

100. Heilig, Robert, M.D., Chief Physician, Jaipur, Rajputana. (1948).

101. Heron, A. M., D.Sc., F.G.S., F.R.G.S., F.R.S.E., F.A.S., Geological Survey of Pakistan, Quetta.

102. Hora, S. L., Rai Bahadur, D.Sc., F.R.S.E., C.M.Z.S., F.Z.S.I., M.I.Biol., F.A.S., Director, Zoological Survey of India, Jabakusum House, 34 Chittaranjan Avenue, Calcutta 12.

103. Husain, M. Afzal, Khan Bahadur, M.A., M.Sc., I.A.S., Chairman, Pakistan Public Service Commission, Karachi.

104. Ishaq, Mohammed, M.Sc., Ph.D., D.I.C., 21 Cooper Road, Lahore. (1940).

105. Iyengar, M. O. P., M.A., Ph.D., F.L.S., University Professor of Botany, Madras University, (retired); 71 Venkatarangam Pillai Street, Triplicane, Madras.

106. Iyer, P. V. Krishna, M.A., D.Phil. (Oxon.), Professor of Statistics, Indian Council of Agricultural Research, Jamnagar House Hutment, New Delhi. (1951).

107. Jacob, K., D.Sc., F.G.S., Palaeontologist, Geological Survey of India, 27 Chowringhee Road, Calcutta 13. (1949).

108. Job, T. J., D.Sc., F.Z.S.I., F.A.S., Assistant Regional Fisheries Officer for Asia and Far East, Regional Fisheries Office of the F.A.O. of U.N., Maliwan Mansian, Phra Atit Road, Bangkok, Thailand.

109. Joshi, A. C., D.Sc., P.E.S.(I.), Principal, Government Training College for Teachers, Jullundur, E. Punjab. (1938).

110. Joshi, S. S., D.Sc. (Lond.), F.R.I.C., F.A.Sc., Principal, College of Science and Head of the Department of Chemistry, Banaras Hindu University, Banaras. (1945).

111. Kadam, B. S., Ph.D., Director, Central Tobacco Research Institute, Rajahmundry, M. & S.M. Ry. (1946).

112. Kapur, S. N., Ph.D., Kapur's Industrial and Research Laboratory, 14/2A Nirode Behari Mullick Road, Calcutta 6.

113. Khan Bhatti, Hamid, M.Sc., LL.B., Ph.D., Head of the Department of Zoology, Punjab University, Lahore. (1944).

114. Khanolkar, V. R., M.D., Director of Laboratories and Research, Tata Memorial Hospital, Hospital Avenue, Parel, Bombay. (1946).

115. Khastgir, S. R., Ph.D., D.Sc., F.R.S.E., Department of Physics, Banaras Hindu University, Banaras. (1944).

116. Khosla, A. N., C.E., I.S.E., Chairman, Central Waterpower, Irrigation and Navigation Commission, Government of India; 1 Clive Road, New Delhi. (1951).

117. Kichlu, P. K., D.Sc., Professor of Physics, Delhi University, Delhi. (1935).

118. Kini, M. G., M.B.B.S., M.Ch. (Orth.), F.R.C.S., Captain, M.C., 3rd Floor, Connaught Mansion, Colaba, Bombay 5. (1944).

119. Kosambi, D. D., S.B. (Harvard), Professor of Mathematics, Tata Institute of Fundamental Research, Apollo Pier Road, Bombay 1. (1946).

120. Kothari, D. S., M.Sc., Ph.D., Scientific Adviser, Ministry of Defence, Government of India; 5 University Road, Delhi. (1936).

121. Krishna, S., C.I.E., Ph.D., D.Sc., Scientific Liaison Officer for India in U.K., India House, Aldwych, London, W.C. 2.

122. KRISHNAN, SIR K. S., Kt., D.Sc., F.R.S., Director, National Physical Laboratory, Hill Side Road, New Delhi 5.

123. KRISHNAN, K. V., M.B.B.S., L.R.C.P., D.B., D.Sc., Professor of Microbiology, All-India Institute of Hygiene and Public Health, 110 Chittaranjan Avenue, Calcutta.

124. KRISHNAN, M. S., A.R.C.S., Ph.D., D.I.C., Director, Geological Survey of India, 27 Chowringhee, Calcutta 13. (1935).

125. KRISHNAN, R. S., Ph.D., D.Sc., Professor of Physics, Indian Institute of Science, Bangalore. (1950).

126. KRISHNASWAMI, K. R., D.Sc., F.R.I.C., Director of Industries, Bihar, Patna. (1948).

127. KUNDU, B. C., Ph.D. (Leeds), F.L.S., Director, Jute Agricultural Research Institute, Indian Central Jute Committee, Hooghly, West Bengal. (1945).

128. LAL, K. B., Ph.D., Entomologist to Government of Uttar Pradesh, Kanpur. (1951).

129. LAL, R. B., M.B.B.S., D.P.H., D.T.M. & H., D.B., Professor of Vital Statistics and Epidemiology, All-India Institute of Hygiene and Public Health, 110 Chittaranjan Avenue, Calcutta. (1935).

130. LAW, S. C., M.A., B.L., Ph.D., F.Z.S., M.B.O.U., 50 Kailas Bose Street, Calcutta. (1936).

131. MACGREGOR, R. A., C.I.E., F.I.M., Technical Director, Indian Special Steel Marketing Board, 4th Floor, P23/24 Radha Bazar Street, Calcutta 1. (1948).

132. MADHAVA, K. B., M.A., A.I.A. (Lond.), Post Box No. 1459, Madras 18. (1940).

133. MAHABALE, T. S., M.Sc., Ph.D., Lecturer in Botany, The Institute of Science, Mayo Road, Bombay. (1949).

134. MAHADEVAN, C., M.A., D.Sc., Professor of Geology, Erskine College of Natural Sciences, Andhra University, Waltair. (1945).

135. MAHAJANI, G. S., M.A., Ph.D., Vice-Chancellor, Rajputana University, 18 Civil Lines, Jaipur.

136. MAHALANOBIS, P. C., O.B.E., M.A., B.Sc., F.R.S., 204 Barrackpore Trunk Road, Calcutta 35.

137. MAHANTI, P. C., D Sc., F.Inst.P., Assoc.A.I.E.E., Ghose Professor of Applied Physics, Calcutta University, 92 Upper Circular Road, Calcutta. (1945).

138. MAHESHWARI, P., D.Sc., Professor and Head of the Department of Botany, Delhi University, Delhi. (1935).

139. MAJUMDAR, D. N., M.A., Ph.D., Professor of Anthropology, Lucknow University, Lucknow. (1940).

140. MAJUMDAR, G. P., Ph.D., Professor of Botany and Head of the Department of Biology, Dacca University, Ramna, Dacca, E. Bengal. (1943).

141. MAJUMDAR, R. C., Dr.Phil.Nat. (Jena), Professor and Head of the Department of Physics Delhi University, Delhi. (1941).

142. MALHOTRA, D. R., D.Sc., A.M.I.Chem.E., F.I.M., M.I.E. (India), Chief Chemist and Metallurgist, B.B. & C.I. Rly., Golf Course Road, Ajmer. (1946).

143. MEHRA, H. R., M.Sc., Ph.D., Head of the Zoology Department, Allahabad University, Allahabad.

144. MITRA, H. K., M.Sc. (Cal.), Ph.D. (Pittsburgh, U.S.A.) Refractories Engineer, Tata Iron & Steel Co., Ltd., 12A Road East, Jamshedpur. (1949).

145. MITRA, K., M.B., D.P.H., D.T.M. & H., F.S.S. (Eng.), Nutrition Adviser, Directorate General of Health Services, New Delhi. (1949).

146. MITRA, SUBODH, M.D., F.R.C.S., F.R.C.O.G., 4 Chowringhee Terrace, Calcutta. (1944).

147. MITRA, S. C., M.A., Ph.D. (Leip.), Lecturer in Psychology, Calcutta University, 92 Upper Circular Road, Calcutta 9. (1941).

148. MITRA, S. K., M.B.E., D.Sc., F.A.S., Ghose Professor of Physics, Calcutta University, 92 Upper Circular Road, Calcutta 9.

149. MITTER, G. C., O.B.E., M.Sc., F.R.I.C., M.Inst.Met., Chief Technical Adviser, Indian Government Mint, Bombay. (1948).

150. MITTER, P. C., M.A., Ph.D., Palit Professor of Chemistry, Calcutta University (retired), 22 Garpar Road, Calcutta.

151. MOGHE, M.A., Ph.D., F.Z.S., Professor of Zoology, Poona University, Ganeshkhind, Poona. (1948).

152. MOOKERJEE, H. K., D.Sc., D.I.C., Sir Nilratan Sircar Professor of Zoology and Head of the Department, Calcutta University, 35 Ballygunge Circular Road, Calcutta 19. (1939).

153. MOWDAWALLA, F. N., M.A., M.I.E.E., Mem.A.I.E.E., M.I.E., 301 Frere Road, Fort, Bombay.

154. MUKERJI, B., D.Sc., Director, Central Drug Research Institute, Chattar Manzil Palace, Lucknow, U.P. (1943).

155. MUKHERJEE, J. N., C.B.E., D.Sc., F.C.S., F.A.S., Director, Central Building Research Institute, Roorkee.

156. MUNDKUR, B. B., Ph.D., Professor of Botany, Poona University, Poona 7. (1946).

157. NAIK, K. G., D.Sc., F.R.I.C., Rector, Gujarat University, Ahmedabad 9.

158. NAIR, U. S., M.A., Ph.D. (Lond.), Head of the Department of Statistics, Travancore University, Trivandrum. (1945).

159. NARAYANA, BASUDEV, M.Sc., M.B., Ph.D., F.R.S.E., Principal and Professor of Physiology, Prince of Wales Medical College, Patna. (1946).

160. NARAYANAMURTI, D., B.Sc., Dr.Ing., Chief Research Officer, Composite Wood and Wood Preservation Section, Forest Research Institute, New Forest, Dehra Dun. (1940).

161. NARLIKAR, V. V., B.Sc. (Bom.), M.A. (Cantab.), F.R.A.S., Professor of Mathematics and Head of the Department, Banaras Hindu University, Banaras. (1939).

162. NATH, M. C., D.Sc., Chitnavis Professor and Head of the Department of Biochemistry, Nagpur University, Nagpur. (1950).

163. NATH, RAJ, Ph.D., D.I.C., University Professor and Head of the Department of Geology, Banaras Hindu University, Banaras. (1943).

164. NATH, VISHWA, M.Sc., Ph.D., F.R.M.S., Principal, Government College, Hoshiarpur. (1940).

165. NEHRU, THE HON'BLE PANDIT JAWAHARLAL, Prime Minister of India, New Delhi. (1947).

166. NORMAND, SIR CHARLES W. B., Kt., C.I.E., M.A., D.Sc., c/o Midland Bank, Gloucester Road, London, S.W. 7.

167. PAL, B. P., Ph.D., F.L.S., Director, Indian Agricultural Research Institute, New Delhi. (1946).

168. PANDIT, C. G., O.B.E., M.B.B.S., Ph.D., D.P.H., D.T.M., Secretary, Indian Council of Medical Research, 'P' Block, Raisina Road, New Delhi. (1939).

169. PANDYA, A. H., Sc.D. (Eng.), M.I.E. (Ind.), M.Am.Soc.C.E., A.M.I.S.E., A.M.I.W., 'Kumkum', 50-A Pedder Road, Bombay 26. (1949).

170. PANJA, G., M.B., D.Bact., Professor of Bacteriology and Pathology, School of Tropical Medicine (retired); P. 117 Vivekananda Road, Calcutta. (1944).

171. PANSE, V. G., Ph.D., Statistical Advisor, Indian Council of Agricultural Research, Jamnagar House, Mansingh Road, New Delhi. (1946).

172. PARANJPE, G. R., O.B.E., M.Sc., A.I.I.Sc., I.E.S. (retired), 'Sudarshan', 202/1 Sadashiv, Poona 2. (1937).

173. PARANJPYE, SIR R. P., Kt., D.Sc., Purushottam Ashram, Poona 4.

174. PARIJA, P., O.B.E., M.A., D.Sc., I.E.S. (retd.), Pro-Chancellor, Utkal University, 10 Cantonment Road, Cuttack.

175. PARTHASARATHY, N., B.Sc. Ag., Ph.D. (Lond.), Geneticist, Indian Agricultural Research Institute, New Delhi. (1949).

176. PASRICHA, C. L., M.A., M.B., B.Chir., M.R.C.S., L.R.C.P., Lt.-Col., I.M.S., Chief Medical Adviser to the High Commissioner for India, India House, Aldwych, London, W.C. 2. (1939).

177. PERCIVAL, F. G., O.B.E., Ph.D., F.G.S., Sadlers Cottage, Haslemere, Surrey, England, (1936).

178. PICHAMUTHU, C. S., Ph.D., D.Sc. (Glasgow), F.R.S.E., F.G.S., Director of Geology, Mysore Geological Department, Bangalore 1. (1942).

179. PRASAD, B. N., Dr. ès Sc., Ph.D., Lakshmi Niwas, George Town, Allahabad. (1936).

180. PRASAD, MATA, D.Sc., F.R.I.C., Principal, The Institute of Science, Mayo Road, Bombay. (1935).

181. PRASHAD, BAINI, O.B.E., D.Sc., F.R.S.E., F.L.S., F.Z.S., F.A.S., Director of Fisheries West Bengal, Writers Buildings, Calcutta.

182. PRUTHI, H. S., Ph.D., Sc.D. (Cantab.), F.A.S., Plant Protection Adviser, Government of India, Ministry of Agriculture; 12 Akbar Road, New Delhi.

183. QURESHI, MUZAFARUDDIN, Ph.D., Pakistan.

184. RACINE, C., S.J., Dr. ès Sc. (Paris), Professor and Head of the Department of Mathematics, Loyola College, Madras. (1949).

185. RAJ, B. SUNDARA, Diwan Bahadur, M.A., Ph.D., Department of Fisheries, Ministry of Industries, Industrial Research and Fisheries, Galle Face, Colombo 3, Ceylon. (1935).

186. RAJU, S. P., B.E., Dr.Ing., M.I.E., 'Hill View', Red Hills, Hyderabad (Deccan). (1948).

187. RAKSHIT, H., D.Sc., F.Inst.P., Professor of Physics, Bengal Engineering College, Botanic Gardens P.O., Howrah. (1943).

188. RAMANATHAN, K. R., Diwan Bahadur, M.A., D.Sc., Physical Research Laboratory, Navarangpura, Ahmedabad.

189. RAMANUJAM, S., Ph.D., Director, Central Potato Research Institute, P.B. No. 136, Patna. (1948).

190. RAMDAS, L. A., M.A., Ph.D., Director of Agricultural Meteorology, Meteorological Office, Poona 5. (1935).

191. RAMIAH, K., M.B.E., L.Ag., M.Sc., Dip.Agr. (Cantab.), Director, Central Rice Research Institute, P.O. Naya Bazar, Cuttack. (1942).

192. RANDHAWA, M. S., M.Sc., I.C.S., Director-General, Rehabilitation (Rural), Civil Secretariat, Jullundur, E. Punjab. (1943).

193. RANGASWAMI AYYANGAR, G. N., Rao Bahadur, B.A., I.A.S. (retired), 'Rama Mandiram', 4 Ramaswamy Street, Thyagarayanagar, Madras 17.

194. RANJAN, SHRI, D.Sc., Professor and Head of the Department of Botany, Allahabad University, Allahabad. (1951).

195. RAO, B. RAMA, M.A., D.I.C., F.G.S., 291, Srivilas, Visvesvarapur, Bangalore.

196. RAO, B. SANJIVA, M.A., Ph.D., D.Sc. (Lond.), Radha Nivas, 10th Main Road, Malleswaram, Bangalore 3. (1944).

197. RAO, H. SRINIVASA, M.A., D.Sc., c/o Imperial Bank of India, Ltd., P.O., Vellore, (N. Arcot). (1937).

198. RAO, K. RANGADHAMA, D.Sc. (Madras and London), Principal, College of Science and Professor of Physics, Andhra University, Waltair. (1937).

199. RAO, L. RAMA, M.A., F.G.S., Professor of Geology, Central College, Bangalore. (1939).

200. RAO, M. V. RADHAKRISHNA, M.B., B.S., Ph.D. (Andhra), Assistant Director, Haffkine Institute, Parel, Bombay. (1945).

201. RAO, S. RAMACHANDRA, Ph.D., D.Sc., Professor of Physics, Central College, Bangalore. (1948).

202. RAO, S. R. NARAYAN, M.A., Professor and Head of the Department of Geology, Lucknow University, Lucknow. (1951).

203. RAY, H. N., Ph.D., Officer-in-charge, Section of Parasitology, Indian Veterinary Research Institute, Mukteswar-Kumaun. (1950).

204. RAY, J. C., M.D., Director, Indian Institute for Medical Research, 15 Roy Mansion, Calcutta 20. (1948).

205. RAY, J. N., D.Sc., Ph.D., F.R.I.C., c/o Teddington Chemical Factory Ltd., Surèn Road, Andheri, Bombay. (1935).

206. RAY, P. M.A., Palit Professor of Chemistry, Calcutta University, 92 Upper Circular Road, Calcutta 9.

207. RAY, R. C., D.Sc. (Lond.), F.R.I.C., Emeritus Professor of Chemistry, Science College, Patna; B.M. Das Road, Bankipore, Patna. (1943).

208. ROONWAL, M. L., M.Sc., Ph.D. (Cantab.), Major, Forest Entomologist, Forest Research Institute, New Forest, Dehra Dun. (1945).

209. ROW, R., M.D., D.Sc., Lt.-Col., I.M.S. (Hon.), 37 New Marine Lines, Fort, Bombay 1.

210. ROY, S. C., D.Sc., F.R.Met.Soc. (Lond.), Deputy Director-General of Observatories (Instruments and Supplies), India Meteorological Department, Lodi Road, New Delhi. (1940).

211. ROY, S. K., Ph.D., In-charge of Development of Coal Mines, Dabor Colliery, P.O. Shamdih, Dist. Burdwan (*via* Sitarampur), E.I. Ry. (1940).

212. ROY, S. N., M.Sc., Institute of Mathematics and Statistics, University of N. Carolina, Chapel Hill, N.C., U.S.A. (1944).

213. SAHA, M. N., D.Sc., F.R.S., F.A.S., Palit Professor of Physics, Calcutta University, 92 Upper Circular Road, Calcutta 9.

214. SAHNI, M. R., M.A., D.I.C., Ph.D., D.Sc., Superintending Geologist, Geological Survey of India, 18 Rana Pratap Marg, Lucknow. (1950).

215. SARKAR, P. B., Dr. ès Sc., A.I.C., Ghose Professor of Chemistry, Calcutta University, 92 Upper Circular Road, Calcutta 9. (1935).

216. Sarkar, P. B., D.Sc. (Dacca), Director of Technological Research Laboratories, Indian Central Jute Committee; P 133B Lake Terrace, Calcutta 29. (1946).

217. Savur, S. R., M.A., L.T., Ph.D., Regional Director, The Observatory, 15 Mowbrays Road, Teynampet P.O., Madras. (1941).

218. Sawhney, K., M.Sc., Secretary, Indian Central Cotton Committee, 14 Nicol Road, Bombay. (1951).

219. Sen, B. M., M.A., M.Sc., I.E.S. (retired), 12 Ballygunge Circular Road, Ballygunge, Calcutta 19.

220. Sen, J. M., Rai Bahadur, B.Sc., M.Ed. (Leeds), Dip.Ed. (Oxford), T.D. (London), F.R.G.S., 28 New Road, Alipur, Calcutta. (1935).

221. Sen, K. C., D.Sc., Director of Dairy Research, Indian Dairy Research Institute, Hosur Road, Bangalore. (1949).

222. Sen, N. K., D.Sc., (Dacca), F.R.I.C., Professor and Head of the Department of Chemistry, Presidency College, Calcutta. (1951).

223. Sen, N. R., D.Sc., Ph.D., Ghose Professor of Applied Mathematics, Calcutta University, 92 Upper Circular Road, Calcutta 9.

224. Seshadri, T. R., M.A., Ph.D. (Manchester), Professor of Chemistry, Delhi University, Delhi. (1942).

225. Setna, S. B., M.Sc., Ph.D. (Cantab.), F.R.M.S., Director of Fisheries, Bombay, Old Custom House Yard, Bombay. (1943).

226. Sewell, R. B. Seymour, Lt.-Col., C.I.E., M.A., Sc.D., F.R.S., M.R.C.S., L.R.C.P., F.Z.S., F.L.S., F.A.S., 18 Barrow Road, Cambridge. (1936).

227. Shah, R. C., M.Sc., Ph.D. (Lond.), Professor of Organic Chemistry, The Institute of Science, Mayo Road, Bombay. (1941).

228. Sharif, M., D.Sc., Ph.D., Professor of Zoology and Director, University Zoology Laboratories, Government College, Lahore, Pakistan. (1939).

229. Siddiqi, M. R., M.A., Ph.D., Director of Research, Peshawar University, Peshawar, Pakistan. (1937).

230. Singh, B. K., M.A., Sc.D., F.R.I.C., I.E.S., Honorary Research Professor of Chemistry, Banaras Hindu University, Banaras.

231. Singh, B. N., D.Sc., Crop Physiologist, Institute of Crop Physiology, U.P. Government, Butler Palace, Lucknow. (1941).

232. Sirkar, S. C., D.Sc., Professor of Physics, Indian Association for the Cultivation of Science, Jadabpur, Calcutta 32. (1942).

233. Sohoni, V. V., B.A. (Hons.), M.Sc., Director-General of Observatories, India Meteorological Department, Lodi Road, New Delhi. (1942).

234. Sokhey, Sir S. S., Kt., M.A., M.D., D.T.M. & H., Major-General, I.M.S., Asst. D.G., W.H.O., Geneva, Switzerland.

235. Sondhi, V. P., M.B.E., M.Sc., F.G.S., Dy. Director (Min. Dev.), Geological Survey of India, 27 Chowringhee Road, Calcutta. (1941).

236. Soparkar, M. B., M.D., B.Hy., 117 Ghodbunder Road, Khar, Bombay 21. (1937).

237. Spencer, E., D.Sc., Ph.D., F.R.I.C., A.R.S.M., M.I.M.M., F.G.S., Ashfield House, Keighley Road, Colne, Lancs., England.

238. Sreenivasan, A., D.Sc., F.R.I.C., Lecturer in Foods and Drugs, Department of Chemical Technology, University of Bombay, Matunga Road, Bombay 19. (1950).

239. Srivastava, B. N., D.Sc., Reader in Physics, Lucknow University, Lucknow. (1946).

240. Srivastava, P. L., Rai Sahib, M.A., D.Phil., Reader in Mathematics, Allahabad University, Allahabad. (1935).

241. Subrahmanyan, V., D.Sc., F.R.I.C., Director, Central Food Technological Research Institute, Cheluvamba Mansion, V. V. Mohalla P.O., Mysore.

242. Sukhatme, P. V., D.Sc. (Lond.), Ph.D., Statistical Adviser, Indian Council of Agricultural Research, Jamnagar House, New Delhi. (1943).

243. Sur, N. K., D.Sc., Professor of Meteorology, Andhra University, Waltair. (1938).

244. Tawde, N. R., M.Sc., Ph.D. (Lond.), F.Inst.P., Professor of Physics, The Institute of Science, Mayo Road, Bombay. (1942).

245. Taylor, Sir John, Kt., C.I.E., D.S.O., M.D., D.P.H., LL.D., Major-General, I.M.S. (retired), 88 Onslow Gardens, Kensington, London, S.W. 7.

246. Toshniwal, G. R., D.Sc., S.M.I.R.E., Managing Director, Toshniwal Bros. Ltd., 4th Floor, Janmabhumi Chambers, Fort Street, Ballard Estate, Bombay 1. (1943).

247. Tribedi, B. P., M.B. (Cal.), D.B. (Lond.), Professor of Pathology, Medical College and Bacteriologist to the Government of West Bengal, Calcutta. (1943).

248. UKIL, A. C., M.B., M.S.P.E., F.S.M.F. (Hon. Causa), F.A.S., 67 Dharamtala Street, Calcutta 13. (1935).

249. UPPAL, B. N., M.B.E., Ph.D., Director of Agriculture, Bombay Province, Poona 5. (1944).

250. VACHELL, E. T., M.A. (Cantab.), F.G.S., F.Inst.P., Coley, Lydwell Road, Torquay, Devon. England. (1942).

251. VARMA, R. S., D.Sc., Senior Scientific Officer, Ministry of Defence, Government of India, South Block, Central Secretariat, New Delhi. (1949).

252. VASUDEVA, R. S., Ph.D., D.I.C., Head of the Division of Mycology and Plant Pathology, Indian Agricultural Research Institute, New Delhi 5. (1950).

253. VENKATARAMAN, K., M.S. Tech., Ph.D., D.Sc., Director, Department of Chemical Technology, Bombay University, Matunga Road, Bombay. (1939).

254. VENKATESACHAR, B., Rao Bahadur, M.A., F.Inst.P., Ambika Vilas, 62 Gandhi Bazar St., Basavangudi, Bangalore.

255. VERMAN, L. C., B.S.Eng., M.S., Ph.D. (Cornell), F.Inst.P., Director, Indian Standards Institution, 19 University Road, Delhi. (1946).

256. VIJAYARAGHAVAN, T., Ph.D. (Oxon), 'Krishna Vilas', Vepery, Madras.

257. VISWANATH, B., D.Sc., F.R.I.C., 'Krishna Nivas', 8A/85, Western Extension, Pusa Road, New Delhi 5.

258. WADIA, D. N., M.A., D.Sc. (Hon.), F.G.S., F.A.S., Geological Adviser to the Atomic Energy Commission, Ministry of Natural Resources and Scientific Research, Government of India; Central Secretariat, Room No. 191-A, North Block, New Delhi.

259. WEST, W. D., C.I.E., M.A., Sc.D. (Cantab.), F.A.S., Highwood Country Club, Ellerslie Lane, Bexhill-on-sea, Sussex, England.

260. WHEELER, T. S., D.Sc., Ph.D., F.R.C.Sc.I., F.R.I.C., F.Inst.P., M.I.Chem.E., Professor of Chemistry, University College of Dublin (National University of Ireland), Upper Merrion Street, Dublin.

261. YAJNIK, N. A., M.A., D.Sc., A.I.C., 24 South Tukoganj, Indore. (1940).

HONORARY FELLOWS

1. APPLETON, SIR EDWARD V., G.B.E., K.C.B., D.Sc., F.R.S., N.L., Principal and Vice-Chancellor of the University of Edinburgh; The Old College, South Bridge, Edinburgh 8. (1939).

2. BAILEY, SIR E. B., Kt., D.Sc., LL.D., F.R.S., Formerly Director-General, Geological Survey of Great Britain; 19 Greenhill Gardens, Edinburgh. (1941).

3. BLAKESLEE, A. F., D.Sc., Ph.D., LL.D., Director of Genetics Experiment Station, Smith College, Northampton, Mass., U.S.A. (1945).

4. BOHR, NIELS, N.L., Director, Copenhagen Institute of Theoretical Physics, Blegdamsvej 15, Copenhagen, Denmark. (1935).

5. BROGLIE, LOUIS DE, D.Sc., N.L., Professor of Theoretical Physics, Poincare Institute, Sorbonne, Paris. (1949).

6. BURN, J. H., M.D., F.R.S., Professor of Pharmacology, Oxford University; South Parks Road, Oxford. (1947).

7. CHRISTOPHERS, SIR RICKARD, Kt., C.I.E., O.B.E., M.D., Brevet-Colonel, I.M.S. (retired), 186 Huntingdon Road, Cambridge. (1940).

8. DALE, SIR HENRY HALLETT, Kt., O.M., G.B.E., M.A., M.D., F.R.C.P., Hon. D.Sc., Hon. M.D., Hon. LL.D., F.R.S., Formerly Director of the Davy-Faraday Research Laboratory and Fullerian Professor of Chemistry in the Royal Institution, London; 54 Campden Hill Court, Kensington, London, W. 8. (1944).

9. DEBYE, P., N.L., Professor of Chemistry, Cornell University, Ithaca, New York, U.S.A. (1950).

10. DIRAC, P. A. M., F.R.S., N.L., Lucasian Professor of Mathematics, Cambridge University, Cambridge. (1947).

11. DONNAN, F. G., F.R.S., Formerly Director, Sir William Ramsay Laboratory, University College, London; Roseneath, Hartlip, near Sittingbourne, Kent, England. (1936).

2. EINSTEIN, ALBERT, N.L., Institute for Advanced Study, Princeton University, 112 Mercer Street, New Jersey, U.S.A. (1935).

3. EULER, HANS VON, N.L., Professor of Chemistry, Stockholm University, Stockholm, Sweden. (1949).

4. FISHER, R. A., Sc.D., F.R.S., Professor of Genetics, Cambridge University; Whittingehame Lodge, 44 Storey's Way, Cambridge. (1939).

15. HILL, A. V., C.H., O.B.E., Sc.D., F.R.S., N.L. Foulerton Research Professor, Biophysics Research Unit, University College, Gower Street, London, W.C. 1. (1944).
16. LAUE, M. VON, N.L., Professor of Theoretical Physics, Berlin University, Berlin, Germany. (1950).
17. LAWRENCE, E. O., Radiation Laboratory, California University, Berkeley, U.S.A. (1941).
18. MARSHALL, SIR GUY A. K., K.C.M.G., D.Sc., F.R.S., Formerly Director, Imperial Institute of Entomology, London; 31 Melton Court, London, S.W. 7. (1935).
19. MILLIKAN, R. A., Emeritus Professor of Physics, California Institute of Technology, Pasadena, U.S.A. (1945).
20. NIGGLI, P., Professor of Mineralogy and Petrology, Federal Polytechnical University and University of Zurich, Zurich. (1945).
21. ROBINSON, SIR ROBERT, D.Sc., F.R.S., N.L., Waynflete Professor of Organic Chemistry in the Dyson Perrins Laboratory, Oxford University, Oxford, England. (1937).
22. RUSSELL, SIR E. JOHN, D.Sc., F.R.S., Formerly Director, Rothamsted Agricultural Experimental Station; Campsfield Wood, Woodstock, Oxfordshire, England. (1938).
23. SCHRÖDINGER, ERVIN, N.L., Professor of Theoretical Physics, Institute of Advanced Studies in Theoretical Physics, Dublin, Eire. (1950).
24. SHAPLEY, HARLOW, M.A., Ph.D., LL.D., D.Sc., D.Litt., Director of Harvard University Observatory and President, American Science Association, Cambridge, Mass., U.S.A. (1949).
25. SHERRINGTON, SIR CHARLES S., O.M., G.B.E., F.R.S., N.L., Formerly Waynflete Professor of Physiology in the University of Oxford; 12 Grassington Road, Eastbourne, Sussex, England. (1935).
26. SIEGBAHN, M., N.L., Professor of Physics, University of Uppsala, Sweden. (1950).
27. SZENT-GYÖRGYI, A., N.L., Professor of Biochemistry, Marine Biological Laboratory, Woodshole, Mass., U.S.A. (1947).
28. TISCHLER, GEORG, Professor, Botanical Institute, University of Kiel, Berlin. (1949).
29. UREY, HAROLD C., N.L., Professor of Chemistry, Institute of Nuclear Studies, University of Chicago, Chicago 37, Illinois, U.S.A. (1947).

CLASSIFIED LIST OF ORDINARY FELLOWS ACCORDING TO SUBJECTS

(Figures represent serial numbers in the List of Fellows above.)

Mathematics.—

6, 16, 24, 31, 36, 43, 47, 56, 83, 88, 91, 97, 104, 106, 119, 132, 135, 136, 158, 161, 171, 173 179, 184, 212, 219, 223, 229, 240, 242, 251, 256.

Physics.—

8, 10, 15, 18, 22, 25, 28, 38, 40, 44, 59, 64, 72, 86, 90, 99, 115, 117, 120, 122, 125, 137, 141, 148, 157, 166, 172, 187, 188, 190, 198, 201, 210, 213, 217, 232, 233, 239, 243, 244, 246, 254, 255.

Chemistry.—

3, 19, 20, 23, 32, 42, 48, 54, 67, 68, 69, 71, 73, 77, 79, 82, 84, 87, 94, 96, 110, 121, 126, 149, 150, 155, 160, 162, 180, 183, 196, 205, 206, 207, 215, 216, 222, 224, 227, 230, 237, 238, 241, 253, 260, 261.

Engineering Sciences.—

7, 41, 81, 116, 131, 142, 144, 153, 169, 186.

Geology.—

1, 9, 49, 57, 58, 75, 76, 80, 85, 101, 107, 124, 134, 163, 177, 178, 195, 199, 202, 211, 214, 235, 250, 258, 259.

Botany.—

2, 5, 12, 17, 27, 29, 30, 35, 37, 45, 55, 62, 63, 105, 109, 111, 112, 127, 133, 138, 140, 143, 156, 167, 174, 175, 189, 191, 192, 193, 194, 218, 231, 249, 252, 257.

Zoology (including Anthropology).—

4, 11, 14, 26, 33, 34, 50, 52, 60, 74, 89, 92, 95, 102, 103, 108, 113, 128, 130, 139, 151, 152, 164, 181, 182, 185, 197, 203, 208, 225, 226, 228.

Physiology.—

13, 21, 39, 46, 51, 53, 61, 65, 66, 70, 78, 93, 98, 100, 114, 118, 123, 129, 145, 146, 147, 154, 159, 168, 170, 176, 200, 204, 209, 220, 221, 234, 236, 245, 247, 248.

APPENDIX II.

COMMITTEES.

SECTIONAL COMMITTEES, 1951.

(1) 'Mathematics' Committee for Mathematics, Astronomy and Geodesy:—

	To serve until Dec. 31
Prof. N. R. Sen (Secretary and Convener)	1951
Dr. P. V. Sukhatme	1951
Prof. P. C. Mahalanobis	1952
Dr. P. L. Srivastava	1952
Prof. A. C. Banerji	1953
Dr. B. N. Prasad	1953

(2) 'Physics' Committee for Physics and Meteorology:—

Prof. S. K. Mitra	1951
Dr. S. K. Banerji (Secretary and Convener)	1951
Dr. D. M. Bose	1952
Prof. D. S. Kothari	1952
Prof. R. C. Majumdar	1953
Dr. B. N. Srivastava	1953

(3) 'Chemistry' Committee for Pure and Applied Chemistry:—

Dr. S. Krishna	1951
Prof. B. B. Dey (Secretary and Convener)	1951
Dr. S. S. Bhatnagar	1952
Dr. J. C. Ghosh	1952
Dr. J. N. Mukherjee	1953
Dr. Mata Prasad	1953

(4) 'Engineering Sciences' Committee for Engineering, Metallurgy, Electrotechnics and kindred subjects:—

Dr. H. K. Mitra	1951
Dr. A. H. Pandya (Secretary and Convener)	1951
Prof. P. C. Mahanti	1952
Mr. F. N. Mowdawalla	1952
Dr. D. P. Antia	1953
Dr. V. M. Ghatage	1953

(5) 'Geology' Committee for Geology, Palaeontology, Mineralogy and Geography:—

Dr. D. N. Wadia (Secretary and Convener)	1951
Dr. P. K. Ghosh	1951
Dr. M. S. Krishnan	1952
Prof. Raj Nath	1952
Dr. J. B. Auden	1953
Dr. M. R. Sahni	1953

(6) 'Botany' Committee for Pure and Applied Botany, Forestry and Agronomy:—

Prof. P. Maheshwari	1951
Dr. P. Parija (Secretary and Convener)	1951
Prof. G. P. Majumdar	1952
Dr. B. P. Pal	1952
Prof. S. P. Agharkar	1953
Prof. S. R. Bose	1953

(7) 'Zoology' Committee for Pure and Applied Zoology and Anthropology including Ethnology:—

	To serve until Dec. 31
Prof. K. N. Bahl	1951
Dr. D. N. Majumdar	1951
Prof. Vishwa Nath	1952
Dr. H. S. Pruthi (Secretary and Convener)	1952
Dr. J. L. Bhaduri	1953
Prof. H. R. Mehra	1953

(8) 'Physiology' Committee for Animal Physiology, Pathology, Bacteriology, Psychology and other Medical and Veterinary subjects:—

Dr. B. Narayana	1951
Dr. M. V. Radhakrishna Rao	1951
Dr. V. R. Khanolkar	1951
Prof. K. N. Bagchi (Secretary and Convener)	1952
Dr. B. B. Dikshit	1952
Prof. J. M. Sen	1952
Dr. R. N. Chaudhuri	1953
Major S. C. A. Datta	1953
Dr. A. C. Ukil	1953

FINANCE COMMITTEE, 1951

The President.	Dr. S. K. Banerji.
The Treasurer.	Prof. P. C. Mahalanobis.
The three Secretaries.	Dr. D. N. Wadia.

GRANTS COMMITTEE

Office-bearers and Conveners of All Sectional Committees.

RESEARCH FELLOWSHIPS COMMITTEE, 1951

The President	*ex-officio.*	Dr. M. S. Krishnan	Geology
The Treasurer		Dr. P. Maheshwari	Botany
The three Secretaries		Dr. B. P. Pal	
Dr. P. L. Srivastava	Mathematics	Dr. D. R. Bhattacharya	Zoology
Prof. S. K. Banerji	Physics	Prof. H. R. Mehra	
Prof. S. K. Mitra		Dr. B. Mukerji	Physiology
Dr. S. C. Roy		Prof. J. M. Sen	
Prof. B. B. Dey	Chemistry	Dr. A. C. Ukil	
Prof. N. R. Dhar			
Prof. P. B. Sarkar			

EDITORIAL BOARD, 1951

Editor of Publications .. Prof. J. M. Sen.

Mathematics	Prof. N. R. Sen.	Botany	Prof. A. C. Joshi.
Physics	Prof. S. K. Mitra.	Zoology	Prof. K. N. Bahl.
Chemistry	Prof. B. B. Dey.	Anthropology	Dr. B. S. Guha.
Geology	Dr. M. S. Krishnan.	Physiology	Prof. K. N. Bagchi.

LIBRARY COMMITTEE, 1951.

The President
The Treasurer
The three Secretaries } *ex-officio*.
and Members of Council resident in Delhi.

STANDING COMMITTEE FOR ORGANIZATION OF SYMPOSIA.

The President
The Treasurer
The three Secretaries

Prof. H. J. Bhabha
Prof. P. C. Mahalanobis
Dr. A. C. Ukil (Convener).

COMMITTEE (WITH POWERS TO CONSULT EXPERTS) TO SUGGEST A PROPER EMBLEM (CREST) FOR THE INSTITUTE AND TO RECOMMEND A SUITABLE DESIGN FOR THE CHANDRA-KALA HORA MEMORIAL MEDAL.

(*Appointed January 1948.*)

The President
The Treasurer
The Secretaries } *ex-officio*.

Prof. H. J. Bhabha.
Dr. S. L. Hora (Convener).
Dr. J. N. Mukherjee.
Major-General S. S. Sokhey.

The Committee was requested to consult, among others, the following:—
Dr. Suniti Kumar Chatterji.
Nawab Zain Yar Jung.

PUBLICATION ADVISORY BOARD.

Editor of Publications (Convener)
and Members of Council resident in Calcutta.

COMMITTEE TO FORMULATE A SCHEME FOR FORMATION OF NATIONAL COMMITTEES IN DIFFERENT BRANCHES OF SCIENCE.

(*Appointed January 1949.*)

Prof. S. P. Agharkar.
Prof. A. C. Banerji.
Prof. D. S. Kothari.
Dr. J. N. Mukherjee (Convener).
Prof. J. M. Sen.
Representatives of Scientific Societies concerned.

BIOLOGICAL BOARD.

Members of Sectional Committees for Botany, Zoology and Physiology.
Such members of Council as are biologists (including physiologists).
Dr. H. S. Pruthi (Convener).

COMMITTEE APPOINTED TO CONSIDER THE SCHEME FOR THE ESTABLISHMENT OF NATIONAL ENTOMOLOGICAL LABORATORY AND SCHEMES IN OTHER SUBJECTS WHICH NEEDED ATTENTION.

Dr. S. L. Hora, President (Convener).
Prof. S. P. Agharkar.
Dr. H. J. Bhabha.
Prof. A. C. Joshi.
Prof. P. C. Mahalanobis.
Dr. J. N. Mukherjee.
Prof. M. N. Saha.
Dr. H. S. Pruthi, (Secretary).

APPENDIX III.

IMPORTANT RESOLUTIONS OF THE COUNCIL.

August 4, 1950.

RESOLVED to accept the recommendation to set up a Biological Board of which the functions shall be:—

(1) To prepare and consider schemes for the development of biological sciences in India in all aspects, pure and applied.
(2) To advise the Council on all biological matters referred to the Institute by the Government of India, State Governments and other organizations.

This Board is to be composed of:—

(*a*) Members of the Sectional Committees for Botany, Zoology and Physiology of the National Institute of Sciences of India.
(*b*) Such members of the Council of the National Institute of Sciences of India as are biologists (including physiologists).
(*c*) The Board shall have power to co-opt any specialists, not necessarily Fellows of the Institute for specific purposes.
(*d*) The convener of the Board shall be appointed by the Council of the National Institute of Sciences of India every year at its meeting in October.

RESOLVED that the Government of India be advised to press for the appointment from India of corresponding members on the Commission of Ports of the International Geographical Union.

RESOLVED that the Government of India be advised to get prepared a National Bibliography on Hydrology for the years 1938 to 1949 and to entrust the work to the Central Board of Irrigation.

October 6, 1950.

RESOLVED that a Steering Committee of three members be appointed for each symposium who will scrutinize and edit papers intended for publication in a separate issue of the Proceedings which will be called the 'Symposium Number'.

January 1, 1951.

RESOLVED to forward the following remarks to the Government of India:—

'The Government of India may be requested to take steps from now for sending delegates to the General Assembly of the International Radio Scientific Union. No delegates are being sent to the General Assemblies of the U.R.S.I. with the result that India is going unrepresented in the Vice-Presidentships and the Presidentships of Commissions.'

APPENDIX IV.

LIST OF PERIODICALS RECEIVED IN 1950-51.

ASIA.

India—

1. Annals of Biochemistry and Experimental Medicine.
2. Annual Report of Bose Research Institute.
3. Annual Report of the Imperial Veterinary Research Institute
4. Annual Report of the Indian Central Cotton Committee.
5. Annual Report of Indian Lac Research Institute.
6. Annual Report of Indian Standards Institution.
7. Annual Return of Statistics relating to Forest Administration in British India for the year 1940-41.
8. Bulletin of the Calcutta Mathematical Society.
9. Bulletin of the National Geographical Society.
10. Bulletin of the Indian Standards Institution.
11. Calcutta Geographical Review.
12. Calcutta Statistical Association Bulletin.
13. Current Science.
14. Defence Science Journal.
15. Eastern Anthropologist.
16. Forest Research in India.
17. Immunity Bulletin.

18. Indian Cotton Growing Review.
19. Indian Dairyman.
20. Indian Farming.
21. Indian Forest Bulletin.
22. Indian Forester.
23. Indian Forest Records.
24. Indian Journal of Agricultural Science.
25. Indian Journal of Dairy Science.
26. Indian Journal of Genetics and Plant Breeding.
27. Indian Journal of Medical Research.
28. Indian Journal of Pharmacy.
29. Indian Journal of Physics.
30. Indian Standards.
31. Indian Journal of Veterinary Science and Animal Husbandry.
32. Indian Medical Gazette.
33. Indian Minerals.
34. Industrial and News Section of the Indian Chemical Society.
35. Journal of the Indian Chemical Society.
36. Journal of the Indian Mathematical Society.
37. Journal of Indian Society of Agricultural Statistics.
38. Journal of Scientific and Industrial Research.
39. Kheti.
40. Mathematics Student.
41. Memoirs of the Indian Meteorological Department.
42. Mysore Geological Department Records.
43. Physics Quarterly.
44. Proceedings of the Indian Academy of Science, Sections A and B.
45. Proceedings of the National Academy of Sciences, Sections A and B.
46. Proceedings of the Society of Biological Chemists.
47. Proceedings of the Zoological Society of Bengal.
48. Progress Report of the Institute of Plant Industry.
49. Quarterly Journal of the Geological, Mining and Metallurgical Society of India.
50. Report of the Botanical Survey of India.
51. Report of the Haffkine Institute.
52. Report of the King Institute of Preventive Medicine.
53. Science and Culture.
54. Scientific Notes of the India Meteorological Department.
55. Seismological Bulletin of the Meteorological Department.
56. Technological Bulletin of the Indian Central Cotton Committee.
57. Technical Reports of the Survey of India.
58. Transactions of the Indian Institute of Metals.
59. Transactions of the Mining, Geological and Metallurgical Institute of India.
60. Vijnan Karmee.

China—

1. Botanical Bulletin of Academia Sinica.
2. Chinese Journal of Experimental Biology.
3. Chinese Journal of Physics.
4. Journal of Chinese Chemical Society.
5. Journal of Chinese Geophysical Society.
6. Science Record.
7. Sinesia.

Indonesia—

1. Annales Bogoriensis (formerly *Ann. Bot.* Garden, Buitenzorg).
2. Reinwardtia (formerly *Bull. Jard. Bot.* Garden).
3. O.S.R. Bulletin.
4. ,, News.
5. ,, Publications.
6. Sarawak Museum Journal.

Japan—

1. Abstracts from Kagakukenkyujo, Hokoku, Tokyo.
2. Collected papers from the Faculty of Science, Osaka University.
3. Insecta Matsumurana, Sapporo.

4. Journal of Japanese Botany.
5. Journal of the Scientific Research Institute, Tokyo.
6. Memoirs of the Faculty of Engineering, Kyushu University.
7. Memoirs of the Faculty of Engineering, Nagoya University.
8. Nagoya Mathematical Journal.
9. Osaka Mathematical Journal.
10. Progress of Theoretical Physics.
11. Tensor.

Philippines—

Philippine Journal of Science, Manila.

AUSTRALASIA.

Australia—

1. Journal and Proceedings of the Royal Society of New South Wales.
2. Papers and Proceedings of the Royal Society of Tasmania.
3. Report of the Department of Mines, Western Australia.

New Zealand—

1. Bulletin of the Auckland Institute and Museum.
2. The New Zealand Journal of Science and Technology, Sections A and B
3. Transactions and Proceedings of the Royal Society of N. Zealand.
4. Records of the Auckland Institute and Museum.

AFRICA.

Union of South Africa—

1. Annals of the South African Museum.
2. Circulars of Union Observatory, Union of S. Africa.
3. Transactions of the Royal Society of South Africa.

Sudan—

Sudan Notes and Records.

NORTH AMERICA.

Canada—

1. Contributions of Dominion Observatory, Ottawa, Canada.
2. Proceedings of the Nova Scotia Institute of Science, Halifax, N.S.
3. Proceedings of the Royal Canadian Institute, Tororto.
4. Proceedings of the Royal Canadian Institute, Series IIIA.
5. Publications of Dominion Observatory, Ottawa.
6. Transactions of the Royal Society of Canada, Ottawa.

United States—

1. American Journal of Physics.
2. Annals of Harvard College Observatory.
3. Annals of the Missouri Botanical Garden.
4. Annals of New York Academy of Sciences, New York.
5. Annual Report of the Harvard College Astronomical Observatory.
6. Annual Report of the Director, Purdue University, Lafayette.
7. Annual Report of the Rockefeller Foundation, New York.
8. Annual Report of the Rockefeller Foundation (International Health Division).
9. Biological Abstracts.
10. Biological Bulletin (Marine Biological Laboratory, Woods Hole).
11. Bulletin of the American Museum of Natural History, New York.
12. Bulletin of the Atomic Scientists.
13. Bulletin of California Agricultural Experiment Station, Berkeley.
14. Bulletin of Cornell University Agricultural Experiment Station.
15. Bulletin of Harvard College Astronomical Observatory.
16. Bulletin of the Geological Survey, U.S. Department of the Interior.

17. Bulletin of the Tropical Plant Research Foundation, Washington.
18. Bulletin of the United States National Museum, Smithsonian Institution.
19. Bulletin of Scripps Institution of Oceanography, University of California, Berkeley.
20. Chemical Abstracts.
21. Chemical Reviews.
22. Circulars of the California Agricultural Extension Service.
23. Circulars of the California Agricultural Experiment Station.
24. Circulars of Harvard College, Observatory.
25. Circulars of Purdue University, Agricultural Experiment Station.
26. Contributions from the U. S. National Herbarium (United States National Museum).
27. F.A.O. Bulletins.
28. Fieldiana—Geology (Chicago Natural History Museum).
29. Fieldiana—Geology (Memoirs), (Chicago Natural History Museum).
30. Harvard Reprints (Harvard College Observatory).
31. Harvard Reprints, Series II (Harvard College Observatory).
32. Hilgardia.
33. Information Bulletin of the Inter-American Institute of Agricultural Sciences.
34. Journal of Chemical Physics.
35. Journal of the Elisha Mitchell Scientific Society, University of Carolina.
36. Journal of the Franklin Institute.
37. Journal of the Optical Society of America.
38. Journal of Physical and Colloid Chemistry, Baltimore.
39. Journal of Research (National Bureau of Standards).
40. Journal of Washington Academy of Sciences.
41. Mathematics Magazine.
42. Mathematics Review (American Mathematical Society).
43. Mathematics Teacher.
44. Memoirs of Cornell University Agricultural Experiment Station.
45. Memoirs of San Diego Society of Natural History.
46. Novitates of American Museum of Natural History.
47. Nucleonics.
48. Nuclear Science Abstracts.
49. Nursery Notes (Department of Horticulture, Ohio State University).
50. Occasional Papers of the California Academy of Sciences.
51. Technical News Bulletin (National Bureau of Standards).
52. Physical Review.
53. Proceedings of the California Academy of Sciences.
54. Proceedings of the Louisiana Academy of Sciences.
55. Proceedings of the National Academy of Sciences of the U.S.A., Washington.
56. Proceedings of U.S. National Museum, Smithsonian Institution.
57. Proceedings (Reprints) of U.S. National Museum, Smithsonian Institution.
58. Proceedings of the Utah Academy of Sciences, Arts and Letters.
59. Professional Papers of the Geological Survey U.S. Dept. of the Interior.
60. Public Health Reports.
61. Public Health Reports (Supplements).
62. Publications in Botany, University of California.
63. Quarterly of Applied Mathematics, Brown University.
64. Quarterly Progress Reports, Research Laboratory of Electronics (M.I.T.).
65. Records of Observations (University of California Oceanographic Observations on the E.W. 'Scripps' Cruises).
66. Tropical Contributions of the Tropical Plant Research Foundation.
67. Science.
68. Scripta Mathematica, New York.
69. Station Bulletin, Purdue University.
70. Technical Reports of Research Laboratory of Electronics (M.I.T.).
71. Transactions of San Diego Society of Natural History.
72. Transactions of the American Mathematical Society.
73. Transactions of the Connecticut Academy of Arts and Sciences.
74. University of Colorado Studies; Series in Anthropology.
75. Zoologica (Scientific Contributions of New York Zoological Society).

SOUTH AMERICA.

1. Anales de la Academia Nacional de Ciencias Exactas, Fisicas y Naturales de Buenos Aires.
2. Anales de la Academia de Ciencias Medicas, Fisicas y Naturales de la Habana.
3. Memorias e Estudos do Museu Zoologico da Universidade de Coimbra.
4. Memorias y Revista de la Academia Nacional de Ciencias, Mexico.
5. Publicacoes do Instituto de Botanica 'Dr. Goncalo Sampaio' da Faculdade de Ciencias de Universidade do Porto.

6. Revista Cubana de Laboratorio Clinico.
7. Trabalhos do Instituto do Botanicas 'Dr. Goncalo Sampaio' Faculdade de Ciencias da Universidade do Porto.

Trinidad—British West Indies

Tropical Agriculture (Imperial College of Agriculture).

Honolulu—Hawaii

1. Pacific Science (The University of Hawaii).
2. Bulletin of Bernice P. Bishop Museum.

EUROPE.

Austria—

1. Sitzungsberichte, Wien. Abteilung 1.
2. Verhandlungen der Geologischen Budesanstalt, Wien.
3. Zentralanstalt fur Meteorologie unde Geodynamik, Wien.

Belgium—

1. Bulletin du Musee Royal d Histoire Naturelle de Belgique, Bruxelles.
2. Union Radio Scientifique Internationale, Bruxelles.

Bulgaria—

Comptes Rendus de l' Academie Bulgares des Sciences, (Mathematiques), Sofia.

Czechoslovakia—

1. Acta Facultatis Rerum Naturalium Universitatis Carolinae, Praha.
2. Memoirs de la Societas Royale des Letters et des Sciences de Boheme, Prague. Class des Sciences.
3. Publications de la Faculte des Sciences de l' Universite—Masaryk, Brno.

Denmark—

1. Det Kgl. Danske Videnskabernes Selskab; Biological Scriften.
2. Det Kgl. Danske Videnskabernes Selskab; Biological Meddelelser.
3. Det Kgl. Danske Videnskabernes Selskab; Matematiske Fysiske Meddelelser.
4. Matematisk Tiddskrift, Copenhagen.

Finland—

1. Acta Botanica Fennica, Helsingfors.
2. Acta Zoologica Fennica, Helsingfors.
3. Memoranda Societatis pro Fauna et Flora Fennica, Helsingfors.
4. Suomalaisen Tiedeakatemain Toimituksia Annales Academiae Scientiarum Fennicae, Helsinki. Series A. Mathematica—Physica.

France—

1. Archives Internationales d' Histoire des Sciences, Nouvelle Series d' Archeion, Paris.
2. Bulletin de la Societe Mathematique de France, Paris.
3. Comtes Rendus hebdomadaires des Seances de l' Academie des Sciences, Paris.
4. La Nature, Paris.
5. U.N.E.S.C.O., Paris; Bulletin for Libraries.
6. U.N.E.S.C.O., Paris; Courier.
7. U.N.E.S.C.O., Paris; Official Bulletin.

Germany—

1. Fiat Review of German Science, Wiesbaden.
2. Schriften des Naturwissenschaftlichen Vereins fur Schleswig Holstein, Kiel

Great Britain—

1. Annals of Tropical Medicine and Parasitology, Liverpool School of Tropical Medicine.
2. Annual Report of British Non-Ferrous Metals Research Association.
3. Annual Report of the Fresh Water Biological Association of the British Empire.
4. Atomic Scientists News.
5. British Science News.
6. Bulletin of the British Non-Ferrous Metals Research Association.
7. Discovery.
8. Endeavour.
9. Fuel.
10. Geophysical Memoirs of Meteorological Office, London.
11. Journal of the Institute of Fuel.
12. Journal of the Royal Artillery.
13. Journal of the Textile Institute Manchester—Proceedings and Transactions.
14. Memoirs and Proceedings of the Manchester Literary and Philosophical Society.
15. Nature.
16. Philosophical Transactions of the Royal Society of London, Series A and B.
17. Physics Abstracts (Section A of Science Abstracts).
18. Plant Breeding Abstracts.
19. Proceedings of the Royal Society of Edinburgh Sections A and B.
20. Proceedings of the Royal Society of London, Series A and B.
21. Reports of the Department of Scientific and Industrial Research of Great Britain.
22. Report of the Nuffield Foundation.
23. Report of Rothamstead Experimental Station.
24. Research.
25. Science Library Bibliographical Series of Science Museum, South Kensington.
26. Science Museum Library; Monthly List of Accessions to the Library.
27. Science Progress.
28. Today.
29. Transactions and Proceedings of the Botanical Society of Edinburgh.
30. Universities Quarterly.

Ireland—

Proceedings of the Royal Irish Academy, Dublin, Sections A and B.

Hungary—

1. Hungarica Acta Physiologica (Academia Scientiarum Hungaricae, Budapest).
2. Termeszet es Technika, Budapest.

Italy—

1. Atti della Societe Italiana di Scienze Naturali e del Museo Civico di Storia Naturale in Milano, Milan.
2. Pubblicazioni della Stazione Zoologica di Napoli.

Netherlands—

1. Jaarboek der Rijksuniversiteit te Leiden, Leiden.
2. Proceedings of the Koninklijke Nederlendse Academie.

Norway—

Bergens Museums Arbok, Bergen.

Poland—

1. Bulletin Internationale de l' Academie Polonaise des Sciences et des Letters, Cracovie.
2. Comptes Rendus Mensuels des Seances de l' classe des Sciences Mathematiques et Naturalles, Cracovie.
3. Fundamenta Mathematicae, Warsaw.

Roumania—

Bulletin de l' Ecole Polytechnique de Jassy, Jassy.

Sweden—

1. Bulletin Mensuel de l' Observatoire Meteorologie de l' Universitite d' Uppsala.
2. Bulletin of the Geological Institution of the University of Uppsala.
3. Chalmers Tekniska Hogskolas Handlingar (Transactions of the Chalmers University of Technology, Gotheburg).
4. K. Lantsbruks Hogskolans Annaler, Uppsala.
5. K. Svenska Vetenskapsakadamiens, Stockholm; Arkiv for Kemi, Mineralogie och Geologie.
6. K. Svenska Vetenskapsakadamiens, Stockholm; Arkiv for Matematik, Astronomi och Fysik.
7. K. Svenska Vetenskapsakadamiens Handlingar, Fjarde Serien.
8. K. Svenska Vetenskapsakadamiens Handlingar, Tredje Serien.
9. Lunds Universitets Arsskrift, New Series.

Switzerland—

1. Archives des Sciences (Societe de Physique et d' Histoire Naturalle de Geneve).
2. Verhandlungen der Naturforschenden Geselleschaft in Basel
3. Verhandlungen der Schweizerischen Naturforschenden Geselleschaft, Bern.
4. Vierteljahrsschrift der Naturforschenden Geselleschaft in Zurich.

U.S.S.R.—

(*Titles translated into English.*)

1. Astronomical Journal of the Academy of Sciences of the U.S.S.R.
2. Biochemistry Journal of the Academy of Sciences of the U.S.S.R.
3. Modern Biological Successes.
4. Bulletin of the Academy of Sciences of U.S.S.R., Series Biologique.
5. Bulletin of the Academy of Sciences of U.S.S.R., Series Economics and Law.
6. Bulletin of the Academy of Sciences of U.S.S.R., Series History and Philosophy.
7. Bulletin of the Academy of Sciences of U.S.S.R., Series Literature and Linguistics.
8. Bulletin of the Academy of Sciences of U.S.S.R., Series Mathematics.
9. Doklady (Comptes Rendus of the Academy of Sciences of the U.S.S.R.).
10. Journal of the Crimean Astrophysical Observatory.
11. Journal of General Biology.
12. Journal of General Physiology.
13. Mathematical Collections.
14. Memoirs of the Academy of Sciences of U.S.S.R.
15. Memoirs (Bestnik) of Ancient History.
16. Microbiology.
17. Nature.
18. Soviet State and Law.
19. Zoological Journal.

APPENDIX

THE NATIONAL INSTITUTE

Receipts and Payments Account

RECEIPTS.

	Rs. A. P.	Rs. A. P.
To Opening Balance as on 1st April, 1950:—		
4% Loan 1960–70 face value Rs.17,000		
3% Conversion 1946 face value Rs.29,600 ..	47,189 3 10	
Imperial Bank of India Current Account	2,48,882 3 11	
Imperial Bank of India Savings Bank Account ..	9,868 14 8	
Imperial Bank of India Fixed Deposit Account ..	50,000 0 0	
Imperial Bank of India Employees Provident Savings Bank Account	3,731 0 0	
Cash in hand	253 14 9	
Postage stamps in hand	46 4 6	
		3,59,971 9 8
To Grant from Government of India	....	2,00,000 0 0
,, Grant from other sources		
(*a*) Calcutta University	500 0 0	
(*b*) Osmania University	600 0 0	
		1,100 0 0
,, I.C.I. Grant for Stipend Research Fellowships ..	....	57,341 15 0
,, I.C.I. Grant for Contingencies Fellowships ..	....	7,167 12 0
,, Admission Fee	....	416 0 0
,, Compounding Fee for Life Membership	....	414 0 0
,, Membership Subscription	....	6,499 0 0
,, Interest on Investments	....	2,384 13 0
,, Sale of Proceedings	....	1,501 4 0
,, Miscellaneous Receipts	....	9 11 0
,, Indian Science Abstract Fund	....	5,000 0 0
,, Advance Calcutta Office Staff (Gross)	....	75 0 0
,, Advance Calcutta Office (Gross)	....	9,215 7 3
,, Advance Delhi Office Staff (Gross)	....	685 0 0
,, Provident Fund Employees	....	851 9 0
,, Income Tax Research Fellowships	....	150 14 0
,, Suspense Account	....	3 0 0
TOTAL ..	....	6,52,786 14 11

KASHMERE GATE,
DELHI.
18th June, 1951

V. .

OF SCIENCES OF INDIA.

for the year ended 31st March, 1951.

PAYMENTS.

	Rs. A. P.	Rs. A. P.
By Expenses Defrayed out of Government Grant of Rs.2 lacs per contra:—		
,, Staff Salaries (including Allowance and Provident Fund)	....	26,768 4 6
,, N.I.S. Research Fellowships	....	1,10,557 10 9
,, Travelling Expenses	....	17,011 15 0
,, Publications:—		
Aid to Publications of other Societies	15,000 0 0	
Institute Publications (including Rs.5,000 transferred to Indian Science Abstract Fund per contra) ..	20,675 12 9	
		35,675 12 9
,, Library Books and Expenses	....	5,584 5 3
,, Rent of Land	....	4,769 11 0
		2,00,367 11 3
By I.C.I. Research Fellowships Administration Expenses	....	7,647 15 6
By I.C.I. Research Fellowship Expenses:—		
(*a*) Stipends	55,399 8 9	
(*b*) Contingencies	4,470 9 3	
		59,870 2 0
By Contribution to Indian Standard Institution ..	....	250 0 0
,, Transfer to Co-operating Academies	....	204 0 0
,, Printing and Stationery	....	1,728 4 3
,, Rent, Rate and Taxes	....	676 5 0
,, Advertisement	....	209 2 0
,, Postage and Telegrams	....	1,685 1 3
,, Conveyance	....	117 9 9
,, Office Equipment	....	899 8 0
,, Income Tax Office Staff	....	106 7 0
,, Income Tax Research Fellows	....	175 7 0
,, Audit Fee	....	150 0 0
,, Bank Charges	....	155 5 0
,, Provident Fund Contribution Employees	....	15 6 0
,, Miscellaneous Expenses	....	1,088 12 6
,, Advance Calcutta Office (Gross)	....	10,000 0 0
,, Advance Calcutta Office Staff (Gross)	....	50 0 0
,, Advance Delhi Office Staff (Gross)	....	1,660 0 0
,, Building (cost up to 31st March, 1951) out of Government grant of Rs.2,00,000 received in 1948-49, 1949-50	....	94,701 5 0
,, Cash and Other Balances:—		
4% Loan 1960–70 face value Rs.17,000		
3% Loan 1946 face value .. Rs.29,600		
	47,189 3 10	
,, Imperial Bank of India in Current Account ..	1,58,266 13 8	
,, Imperial Bank of India in Savings Bank Account ..	8,836 12 8	
,, Imperial Bank of India in Fixed Deposit Account ..	52,000 0 0	
,, Imperial Bank of India Employees Provident Fund Savings Bank Account	4,582 9 0	
,, Cash in hand	130 6 9	
,, Postage Stamps	22 11 6	
		2,71,028 9 5
TOTAL ..	....	6,52,786 14 11

Examined and found correct.
Sd. S. VAIDYANATH AIYAR & Co.
Chartered Accountants.

DETAILS OF FUNDS 1950-51.

(a) *Funding Account ending 31st March, 1951.*

	Rs.	A.	P.		Rs.	A.	P.
To Balance	52,486	0	6	By Balance as on 1-4-1950 ..	51,656	0	6
				,, Admission Fee during 1950-51	416	0	0
				,, Compounding Fee 1950-51	414	0	0
TOTAL ..	52,486	0	6	TOTAL ..	52,486	0	6
				By Balance	52,486	0	6

(b) *Imperial Chemical Industries (India) Research Fellowship.*

[The Imperial Chemical Industries (India) offered a sum of Rs.3,36,000 in 1945 for award of research fellowships in Chemistry, Physics and Biology to persons resident or domiciled in India to be held at Indian Universities or institutions spread over a period of seven years.]

(i) *Administration Fund.*

	Rs.	A.	P.		Rs.	A.	P.
To expenses during the year	7,647	15	6	By Balance as on 1-4-1950 ..	42,005	1	0
,, Balance	34,357	1	6				
TOTAL ..	42,005	1	0	TOTAL ..	42,005	1	0
				By Balance	34,357	1	6

(ii) *I.C.I. Research Fellowship.*

	Rs.	A.	P.		Rs.	A.	P.
To Payments during the year	59,870	2	0	By Balance as on 1-4-1950 ..	4,462	14	9
,, Balance	9,102	7	9	,, amount received during the year	64,509	11	0
TOTAL ..	68,972	9	9	TOTAL ..	68,972	9	9
				By Balance	9,102	7	9

(c) *Chandrakala Hora Memorial Medal Endowment.*

[Dr. S. L. Hora and Mrs. V. Hora endowed a sum of Rs.3,000 in 1945 in memory of their daughter for bestowal of a medal quinquennially on the person who has made conspicuously important contributions to the development of fisheries in India during the five years preceding the year of award.]

	Rs.	A.	P.		Rs.	A.	P.
To Balance	3,540	0	0	By Balance as on 1-4-1950 ..	3,446	0	0
				,, Interest on 3% G.P. Notes 16-3-1950 to 15-3-1951	90	0	0
				,, interest 1% on amount in Saving Account ..	4	0	0
TOTAL ..	3,540	0	0	TOTAL ..	3,540	0	0
				By Balance	3,540	0	0

(d) *Grant for National Register of Scientific and Technical Personnel in India.*

[The Council of Scientific and Industrial Research made a grant of Rs. 10,000 for preparation of a National Register of Scientific and Technical Personnel in India.]

	Rs.	A.	P.		Rs.	A.	P.
To expenditure up to 1949 ..	6,385	9	6	By amount received ..	5,000	0	0
,, expenditure during 1950	3,526	12	6	,, amount during 1950 ..	5,375	0	0
,, Balance	462	10	0				
TOTAL ..	10,375	0	0	TOTAL ..	10,375	0	0
				By Balance	462	10	0

(e) *Indian Science Abstract Fund.*

	Rs.	A.	P.		Rs.	A.	P.
To Balance	20,000	0	0	By Balance as on 1-4-1950 ..	15,000	0	0
				,, amount during the year	5,000	0	0
TOTAL ..	20,000	0	0	TOTAL ..	20,000	0	0
				By Balance	20,000	0	0

(f) *Building Fund Account.*

	Rs.	A.	P.		Rs.	A.	P.
To expenses during 1948-49	9,767	4	6	By amount of Grant ..	2,20,000	0	0
,, expenditure up to 31-3-1951	94,701	5	0				
,, Balance	1,15,531	6	6				
TOTAL ..	2,20,000	0	0	TOTAL ..	2,20,000	0	0
				By Balance	1,15,531	6	6

(g) *Employees Provident Fund A/c.*

	Rs.	A.	P.		Rs.	A.	P.
To Balance	4,582	9	0	By Balance as on 1-4-1950 ..	3,731	0	0
				,, amount during the year	851	9	0
TOTAL ..	4,582	9	0	TOTAL ..	4,582	9	0
				By Balance	4,582	9	0

(h) *Accountant's Security.*

	Rs.	A.	P.		Rs.	A.	P.
To General Fund ..	3	0	0	By amount as on 1-4-1950 ..	2,003	0	0
,, Balance	2,000	0	0				
TOTAL ..	2,003	0	0	TOTAL ..	2,003	0	0
				By Balance	2,000	0	0

APPENDIX

Budget Estimates for 1951-52 together with

RECEIPTS.

I—GOVERNMENT

	1950-51 Revised Estimates	1950-51 Actuals	1951-52 Estimates
	Rs.	Rs.	Rs.
Government Grant	2,10,170	2,00,000	3,23,025
TOTAL ..	2,10,170	2,00,000	3,23,025

II—I.C.I. RESEARCH

	Rs.		Rs.		Rs.
1. Stipend	53,200		57,342		43,900
2. Contingencies for Research Follows	6,100		7,168		5,600
3. Administration	11,000	(By transfer)	7,648	(By transfer)	13,200
TOTAL ..	70,300		72,158		62,700

III—GENERAL

	Rs.	Rs.	Rs.
1. Admission Fee	480	416	480
2. Compounding Fee	414	414	500
3. Membership Subscriptions ..	6,080	6,499	6,200
4. Contribution Calcutta University	500	500	500
5. Contribution Osmania University	300	600	300
6. Interest on Investments ..	2,400	2,385	2,300
7. Sale of Publications	1,500	1,501	1,500
8. Miscellaneous	25	13	10
9. Transfer from Science Abstracts Fund	3,000	..	15,000
TOTAL ..	14,699	12,328	26,790

VI.

Revised Estimates and actuals for 1950-51.

EXPENDITURE.

GRANT IN AID

		1950-51 Revised Estimates	1950-51 Actuals	1951-52 Estimates
		Rs.	Rs.	Rs.
1.	Staff including allowances and Provident Fund ..	26,800	26,768	35,400
2.	Travelling Expenses	17,200	17,012	17,000
3.	N.I.S. Research Fellowships	1,20,000	1,10,558	1,20,000
4.	Library	7,400	5,584	10,000
5.	Publications—			
	(i) Institute	19,000	20,676	20,000
	(ii) Other Societies	15,000	15,000	15,000
6.	Aid to other Societies	....	....	1,00,000
7.	Rent of building land	4,770	4,770	5,625
	TOTAL ..	2,10,170	2,00,368	3,23,025

FELLOWSHIP

		Rs.	Rs.	Rs.
1.	Stipend	53,200	55,400	43,900
2.	Contingencies	6,100	4,471	5,600
3.	Administration	11,000	7,648	13,200
	TOTAL ..	70,300	67,519	62,700

FUND

		Rs.	Rs.	Rs.
1.	Investment Account (Admission and Compounding Fee: Chandrakala Hora Memorial) ..	984	924	1,070
2.	Contribution Indian Standard Institution ..	250	250	....
3.	Transfer to Co-operating Academies ..	240	204	240
4.	Printing and Stationery	3,000	1,728	3,250
5.	Rent, Rate and Taxes	1,000	676	800
6.	Advertisement	460	209	450
7.	Postage and Telegrams	1,500	1,685	1,760
8.	Conveyance	160	118	150
9.	Office Equipment	2,595	900	2,760
10.	Audit Fee	150	150	150
11.	Bank Charges	160	155	160
12.	Miscellaneous	1,200	1,089	1,000
13.	Publication of			
	(i) Progress of Science in India (in place of Indian Science Abstract)	3,000	....	....
	(ii) Year Book	....	....	15,000
	TOTAL ..	14,699	8,088	26,790

APPENDIX VII.

Summaries of Research Reports of Research Fellows.

(1)

NATIONAL INSTITUTE OF SCIENCES SENIOR RESEARCH FELLOWSHIP.

ANNUAL REPORT.

Name of Research Fellow .. Dr. A. B. Kar.
Subject of Research .. Endocrinology with special reference to birds.

(July 1, 1947—June 30, 1950.)

During the year 1949-1950 the research activities of Dr. A. B. Kar have been directed mainly towards the studies on Physiology and Cytochemistry of hormone action. A summary of the investigations carried out during this period is presented herewith:

A. Studies in the distribution and concentration of alkaline phosphatase in the adrenal cortex of normal and of sex hormone treated pigeons.

The distribution and concentration of alkaline phosphatase has been studied cytochemically in the adrenal cortex of normal and of sex hormone treated pigeons. In normal pigeons there are considerable quantities of the enzyme in the cortical strands in the central region of the gland. In the peripheral cortical strands, however, there is very little enzymatic activity. Treatment with sex hormones (2·5 mgm. of estradiol dipropionate or testosterone propionate intramuscularly injected daily for 10 days) reduce the concentration of cortical phosphatase. However, the degree of this reduction is more pronounced in the estrogen-treated birds than in those receiving androgen. The possible cause of this difference in action between the two hormones has been studied.

B. Studies in the distribution of glycogen in the avian oviduct.

The application of 'Best carmine technique' reveals that there is very little glycogen in the inactive oviduct of juvenile pigeons. Progesterone treatment (0·1 mgm. intramuscularly injected daily for 24 days) has practically no effect on the glycogen content of the oviduct as revealed by this test. Desoxycorticosterone acetate (0·1 mgm. intramuscularly injected daily for 24 days), however, causes an increase in the glycogen content of the oviduct particularly in the hyperplastic mucosal folds. The physiological rôle of glycogen in the oviduct has been studied.

C. Studies in the distribution and concentration of alkaline phosphatase in the oviduct of normal and of steroid hormone treated pigeons.

Cytochemical studies have revealed that there is very little or no alkaline phosphatase in the oviduct of normal juvenile pigeons. The enzyme activity, however, is spectacularly increased in the oviduct of birds treated with estradiol dipropionate (2·5 mgm. injected daily for 10 days). Testosterone propionate (2·5 mgm. daily for 10 days) or DCA (0·1 mgm. daily injected for 24 days) treatments are less effective in augmenting the oviducal phosphatase activity. Unlike these hormones, progesterone (0·1 mgm. injected daily for 24 days) causes a total loss of enzyme activity in the duct. The possible physiological rôle of the phosphatases in the avian oviduct has been studied.

D. Studies in the distribution and concentration of alkaline phosphatase in the avian ovary.

In the ovary of normal pigeons alkaline phosphatase is demonstrable in the theca, endothelium of the blood vessels and the stromal tissue. Androgen treatment (2·5 mgm. testosterone propionate injected daily for 10 days) or DCA (0·1 mgm. injected daily for 24 days) cause a heavy mobilization of the enzyme in the theca. Administration of progesterone (0·1 mgm. injected daily for 10 days), however, causes a loss of phosphatase activity in the ovary. The marked increase in phosphatase activity in the ovarian theca of the testoid or the corticoid-treated birds is indicative of the rôle the phosphatase may play in the synthesis of estrogenic hormones in the ovary.

Studies in the distribution and concentration of alkaline phosphatase in the uropygial gland of normal and of androgen treated pigeons.

Alkaline phosphatase is present in diffuse quantities in the uropygial gland of the pigeon. Androgenic treatments (2·5 mgm. testosterone propionate injected daily for 10 days) depress the activity of the enzyme but do not abolish it. This finding suggests that the holocrine lipoidal cycle in this sebaceous type of gland is mediated by the phosphatase through the influence of sex hormone.

Research publications

(1) Studies on cytochemistry of hormone action. *Part I.* Alkaline phosphatase in the uropygial gland of normal and of androgen treated pigeons. *Part II.* The distribution and concentration of alkaline phosphatase in the ovary of normal and of androgen treated pigeons. *Proc. Nat. Inst. Sci. India*, **16**, 41–45, 1950.

(2) Studies on cytochemistry of hormone action. *Part III.* The effect of progesterone and desoxycorticosterone acetate on the distribution and concentration of alkaline phosphatase in the genital system of female pigeons. *Proc. Nat. Inst. Sci. India*, **16**, 1950, pp. 177–80.

Name of Research Fellow .. Dr. L. S. Ramaswami.

Subject of Research .. The anatomy and embryology of some common food-fishes.

(March 1, 1950—February 28, 1951.)

THE EMBRYOLOGY AND MORPHOLOGY OF THE FOOD-FISHES OF MYSORE.

The embryology and morphology of the food-fishes of India are very inadequately known and even in those cases where the embryology is worked out, the other aspect is neglected. Needless to say that in fishery science, the two disciplines mentioned above are very necessary. In order to fill this lacuna in our knowledge, I took up the study of the embryology and morphology of the food-fishes of India.

The collection of literature bearing on the subject was not an easy matter and with great difficulty I have been able to gather the references necessary from the libraries at Madras, which, however, helped me to write up my first two papers.

During the first year of my tenure as a Fellow, I was considerably assisted by the Zoological Survey of India and the director very kindly placed at my disposal abundance of fish material, which kept me busy. I must express my gratitude to him in this connexion. Moreover, during my excursions to collecting areas like Bethmangala, Hesarghatta and Markandeya tank, I brought a rich collection of fish fauna which has been sorted out and identified. I am happy to say that a new species has also been discovered.

I studied the morphological aspects of *Gyrinocheilus* Vaillant and *Psilorhynchus* McClelland, the two types of the families Gyrinocheilidae and Psilorhynchidae. Both these genera are hill-stream forms and *Psilorhynchus* also lives on sandy bottom. The study has brought out many interesting features, many of which are adaptations to a mountain brook-life. Particularly, I should like to mention that the structure of the first four Vertebrae and the Weberian ossicles of *Gyrinocheilus* resemble more those of the Catostomidae, a group which is not all represented in India. My studies have fully confirmed the earlier conclusions reached by systematic studies that the two genera *Gyrinocheilus* and *Psilorhynchus* have to be treated as types of independent families, Gyrinocheilidae and Psilorhynchidae under the Cyprinoidea. My two papers discussing the systematics of these two fishes are pending publication in the *Proceedings of the National Institute of Sciences of India.*

Dr. S. L. Hora, who visited Bangalore during September 1950, scrutinised my work and offered valuable suggestions. He also discussed with me many of my findings and their bearing on systematics.

I am now engaged on the study of the Homalopterid fishes, another group of fish inhabiting torrential streams. During the course of my work, I have noticed exceedingly interesting features. The skeletal anatomy has further emphasised the origin of the Homalopteridae from Cyprinid-like ancestors, amply supporting the observations of systematists. Peculiarly, I have also noticed the occurrence of a small posterior portion of the gas-bladder whose absence was considered as a general character of the family Homalopteridae. Sufficient indication is found from the viewpoint of skeletal anatomy in support of taxonomical observations that the Homalopteridae should be treated as a separate family and should not be mixed up with the Gastromyzonidae. As soon as the work is over, the paper will be submitted to the *Proceedings* for publication.

FINAL REPORT.

Name of Research Fellow .. Mr. U. R. Burman.
Subject of Research .. Internal constitution of stars.

(May 17, 1949—April 16, 1950.)

The importance of the study of Stellar models with a discontinuous change of chemical composition across the convective-radiative interface has previously been stressed by the present writer. He has recently completed the work on the problem of the détermination of the chemical composition of a star from a knowledge of its mass radius and luminosity on the basis of a convective-radiative model with a sharp discontinuity of composition (molecular weight) across the interface. The energy generation law of Bethe has also been made use of in these calculations. It has been found that just as many equations governing the structure of the star can be framed as there are unknown quantities required for a complete specification of the chemical composition both inside and outside the convective core. It has also been found that stability consideration sets an upper limit to the size of the convective core for the correct model. It is, however, necessary to note that the equations referred to above should not always furnish a significant solution compatible with all the conditions of the problem. In fact, the case of the star α-Cen A worked out by the writer leads to no admissible solution. These results have been incorporated in a paper sent for publication in the *Proceedings of the National Institute of Sciences of India* in March 1950.

The writer is now working on another problem concerning the structure of red giant stars and no pronouncement regarding the results can be made at this stage of the work.

NATIONAL INSTITUTE OF SCIENCES JUNIOR RESEARCH FELLOWSHIPS.

ANNUAL REPORT.

Name of Research Fellow .. Mr. B. K. Banerjea.
Subject of Research .. Propagation of e.m. waves in upper atmosphere.

(October 1, 1949—September 30, 1950.)

A connected discussion of the equations for the vertical propagation of e.m. waves in the ionosphere is given in standardised notation. It is shown that the electric field vector components E_x and E_y are coupled by polarisation terms ρ_1, ρ_2 which are functions of G.M. latitude and height; and the propagation vectors, V and W, equal respectively to $(E + i\rho E_y)/\sqrt{1+\rho^2}$, for two values of ρ, and governed by two refractive indices q_o, q_e and a coupling term ϕ; V and W may be identified with o- and e- waves respectively. The five quantities needed to define wave propagation completely are ρ_1, ρ_2, ϕ, q_o and q_e; we have given a detailed discussion of the first three, and have omitted discussions about q_o and q_e which are identical with those given by Appleton and have been discussed in detail by Booker (1935) and others. It is shown that the coupling term ϕ can be neglected everywhere for F-layer propagation except very near the G.M. poles, while the E-layer propagation is more difficult to handle.

Name of Research Fellow .. Dr. K. Subramanyam.
Subject of Research .. Embryology and floral anatomy in some members of Melastomaceae and embryology of Lobeliaceae, Campanulaceae and Stylediaceae and the interrelationship of these families.

(July 2, 1949—July 1, 1950.)

Some observations were made on the structure of the nectary in the stamens of *Memecylon Heyneanum*, a member of the family Melastomaceae. The stamens of this family are characterised by the presence of peculiar appendages on the connectives of anthers. These appendages are horn-shaped and bluish in colour. Each appendage bears a nectary facing the style in the bud. An account of the structure of the nectary and its vascular supply is described. These observations are published in a note in *Current Science*, 18, 415-416, 1949. (A reprint of this note is enclosed along with this.)

The next work is on An Embryological Study of *Levenhookia dubia* Sond. in Lehm, a member of the Stylidiaceae. The material used in this study was collected from a damp pasture land at Melbourne, South Australia, by Mr. O. D. Evans and Mr. J. H. Willis, who very kindly passed it on to me for investigation. As is characteristic of Stylidiaceae, the flower of *Levenhookia* has a column with a nectary at its base. In *Stylidium graminifolium* (Subramanyam, 1951) two prominent nectaries are present at the base of the column. Stalked multicellular glands are present on the parts of the flower in both genera.

The ovary is unilocular with a number of ovules borne on a free central placenta. The ovules in the upper region of the placenta are anatropous but those below are hemitropous. This appears to bear some relation to the breadth of the locule which is greatest in the upper region but narrow towards the base. The tendency towards a unilocular condition in members of this family is very significant since it points the way towards the unilocular ovary of the Compositae. Another interesting feature noticed in a longitudinal section of the ovary of *Levenhookia dubia* is the presence of a ribbed projection hanging from the base of the column into the locule of the ovary.

The development and structure of the microsporangium of *Levenhookia* closely resembles that of *Stylidium*. In many anthers of the former the pollen grains were found to have germinated *in situ* as in *S. graminifolium* (Subramanyam, 1951) and in some members of the closely allied family Lobeliaceae (Kausik and Subramanyam, 1945; Subramanyam, 1949).

The development of the embryo sac conforms to the Polygonum type. The antipodals persist during the early stages of endosperm development. The lower end of the embryo sac grows past them as a very delicate process, penetrating into the chalaza as in *S. graminifolium* (Subramanyam, 1951).

The endosperm is cellular and the course of divisions closely resembles that in *Stylidium* (Rosén, 1935, 1949; Subramanyam, 1950). At the eight-celled stage of the endosperm, the two upper and the two basal cells develop into the micropylar and chalazal haustoria respectively. In later stages the micropylar haustorium gives out lateral processes which grow in between the parenchymatous cells of the integument as in *S. graminifolium* (Subramanyam, 1951). Such a tendency has also been seen in certain members of the Orobanchaceae (Crété, 1942; Tiagi, 1950) and Plantaginaceae (Crété, 1942). The two-celled chalazal haustorium develops long tubular prolongations which grow in between the cells of the integument. In *S. graminifolium* (Subramanyam, 1950) the chalazal haustorium is made up of two uninucleate cells and both form a number of processes which grow in between the cells of the integument. In *S. adnatum* and *S. graminifolium* (Rosén, 1935, 1949), however, the chalazal haustorium is not so well developed.

The development of the embryo corresponds broadly to the Solanad type of Johansen (1945). The penultimate cell forms the hypophysis. In *S. graminifolium* (Subramanyam, 1950) the four terminal cells of the filamentous proembryo take part in the formation of the different regions of the embryo. A detailed account of the embryology of this plant is published in the *Proceedings of the National Institute of Sciences of India*, **16**, 4, 245–253, 1950. (A reprint of this paper is enclosed along with this.)

The next work is on the Origin and Nature of Haustoria in *Lobelia cardinalis* L., a member of the family Lobeliaceae. Material of open flowers and young fruits of this plant was collected at my request by Dr. V. Puri of Meerut (who was then at U.S.A.) from the Campus of the Cornell University on July 25th, 1949, and fixed in formalin-acetic-alcohol.

The pollen tube destroys one of the synergids. The other synergid also degenerates after fertilisation. The antipodals persist during the early stages of endosperm development. The endosperm is cellular and follows the Scutellaria type of development as in other species of *Lobelia*. One case showing the Phyteuma type of development was noticed. At the eight-celled stage of the endosperm the two terminal cells at each end develop into the micropylar and the chalazal haustoria respectively. The haustoria do not arise from the synergids and antipodals as described by Cooper. This paper has been published in the *Botanical Gazette* in March 1951.

Name of Research Fellow .. Mr. D. K. Mukherji.

Subject of Research .. Plant physiology as applied to plant breeding (Embryo-culture).

(July 7, 1949—July 6, 1950.)

1. During the period under review, work was done on various aspects of plant physiology, plant breeding and genetics with special reference to embryo-culture.

2. Various media used by different workers for studying embryo-growth and tissue-culture had been tried. An improved and modified medium formulated by the author has proved to be of the greatest advantage in serving as the standard medium (S.M.).

3. After trials with various seed-sterilizing agents, a new method has been evolved by using 2% mercuric chloride in 50% alcohol which did not inhibit seed germination to any slightest extent.

4. It was found most suitable to excise embryos out of the seeds that had been soaked in water for 16 hours, inside a culture-room provided with a germicidal ultraviolet lamp and with perfect sterilizing equipments. Hard glass test tubes proved very convenient for the culture work. Culture tubes were kept inside a temperature-controlled chamber.

5. Transplantation of seedlings from the culture tubes to the soil was the most critical phase in the life-span of the seedlings. Of the various methods tried, a method based on the gradual exposure of seedlings to the field conditions proved to be the best one. This method necessitated the transference of the seedlings from the culture tubes to a similar liquid medium, then to the sand supplied with the same liquid medium, and finally to the soil.

6. A study of the seeds of wheat and other crops showed that in some cases like, swede and turnip, there were distinctive features of the embryos, and that in most of the cases the seed coats determined the water-absorbing capacities of the seeds to a great extent. It was also found that out of the three varieties of wheat (*T. vulgare*) studied, N.P. 165 had the highest fresh and dry matter content in the seedlings developed from the embryos grown in cultures.

7. Cultures of embryos excised out of the soft, dry, or shrivelled seeds were all successful. A grooved glass slide was prepared which was found convenient for dissection of embryos from soft or from dry seeds. The soft seeds and their embryos, when cultured, gave rise to more contamination than the dried ones; and the embryos, excised from dry seeds, developed weaker seedlings than those from the soaked ones. Culture of embryos from shrivelled seeds led to plants which were less vigorous, and in most cases, later in flower-production.

8. Vitamin B_1 influenced embryo-growth to a considerable extent. Toxicity was observed at its higher concentrations, whereas at lower concentrations, it enhanced growth, especially that of the roots of the seedlings developed from the embryos. Toxicity involved the development of many abnormal structures, such as, bifurcation of leaves, inverse growth, due to disturbed polarity, etc.

9. An examination of the samples of foodgrains obtained from the local vendors showed as high as 66 to 67% of impurities. Germination capacity of the samples also varied from 50 to 100%.

10. Seeds of different ages were collected from plants of 16 species of *Triticum*, 2 of *Aegilops*, 5 of *Agropyron*, 1 of *Secale*, and 19 strains of *T. vulgare*. Over and above, a number of crosses have been made involving *T. vavilovii*, *T. compactum*, *T. polonicum*, *T. turgidum*, *T. dicoccum*, and *T. monococcum*, and N.P. 4, N.P. 114, N.P. 165, and C.P.H. 47 strains of wheat. Varietal differences in seed and embryo development which are due to genetic constitution and material influences, have been investigated upon. Inheritance of factors responsible for the differences in the response of the embryos to vitamin B_1 and the standard nutrient medium has been planned for study. An abnormally gigantic wheat plant, having larger leaf and ear sizes, has been isolated from a group of plants raised through embryo-culture and treated with vitamin B_1. The seeds will be sown this season for inheritance study for the investigation of the causes of such gigantism, either genetic or physiological.

11. Two papers have been sent for publication and another two are ready for publication.

Final Report.

Considerable progress was done during the period under review on the study of the rôle of vitamin B_1 and ascorbic acid on the nutrition of the plant embryos, and the genetic factors responsible for the variability with regard to the response of the embryos to specific nutrient media.

In addition to the effects of vitamin B_1 on embryo growth *in vitro* in producing abnormalities at higher concentrations and enhanced growth at optimum concentration, it was observed that the effects of this particular vitamin are variable in different varieties of wheat. It is also interesting to note that the hybrid embryos, when grown *in vitro* in nutrient media supplemented with vitamin B_1, showed much more vigour of growth than the embryos of their parents. This result may be explained on the basis of hybrid vigour. It was previously found that there were considerable differences in the behaviour of the embryos with regard to their reaction to any particular nutrient medium, and that these differences were specific to particular varieties and species. All these suggest that the genic constitution of a plant influences the reaction of its embryos to nutrient media, particularly marked in those supplemented with vitamin B_1 This leaves much work to be done to provide sufficient evidence to this view. The F_2 generation will have to be studied in this connection to show whether there is any segregation of the reactivity of the embryos to the nutrient media, especially to those supplemented with vitamin B_1. It is intended to pursue this line of work further.

A preliminary work on the effect of ascorbic acid on embryo culture revealed that although there were some enhancing and retarding effects similar to those of the vitamin B_1, there was no marked specificity of reaction on wheat embryo-growth similar to that of the latter vitamin.

Investigations into the techniques of grafting of embryos have been done. Embryos, excised from dry seeds as well as from soaked ones, have been grafted on to the endosperms of the seeds of other varieties and species. In some cases, there were clear evidences of the increased growth of the transplanted embryos, while in a few others, there was a retarding influence. Although not

markedly distinct in all the cases, it was found in general, that the embryos of hexaploid wheats, when grafted on to the endosperm of the diploid ones, showed a retarding effect on the growth, whereas in the reverse case there was an enhancing effect. This also leaves a scope for work in this line to co-ordinate the behaviour of the grafted embryos with the genetic constitution of the plants.

Seeds, collected from local vendors while on tour to Simla, were tested for their purity, germinating capacity, etc. This is the second of a series of work in this line intended to be done.

Name of Research Fellow .. Mr. B. V. Sukhatme.

Subject of Research .. Theory of Non-Parametric Tests and its applications.

(May 23, 1949—September 28, 1950.)

The research work was done mainly along two lines.

(1) *Probability distributions of points on a line.*

Mood (1940) has dealt at length with the distribution theory of runs. Later on Krishna Iyer (1948) discussed a number of distributions relating to joins between points of the same colour or different colours. None of the authors has, however, discussed the distributions on the basis of higher cumulants. A detailed study along these lines of some of these distributions has now been made and it has been found that the distributions tend to the normal form when the total number of points on the line is sufficiently large, except when the probability of the points taking a particular colour is very small, in which case they tend to the Poisson form. Besides these the probability distributions for triplets and quadruplets have also been derived and the results generalised to s-plets.

(2) *Probability distributions of points on a lattice.*

The distributions considered are those relating to the number of joins between points of the same colour or of different colours. All possible joins between adjacent points have been considered. The distributions tend to the normal form as the size of the lattice increases. Also the exact expressions giving the expected number of triplets and its variance have also been obtained. These results can be used for testing the departure from randomness of a given distribution of diseased plants in a field. It has been found that the test based on the number of triplets including the diagonals is more efficient than that excluding the diagonals.

Some of the results given above have already been published and others are under preparation.

(1) 'Random association of points on a lattice.' *J. Ind. Soc. Agric. Stat.*, **2**, 1, 1949.
(2) 'Variance of triplets.' *Nature*, **164**, 841, 1949.
(3) 'Probability distribution of points on a line.' *Science and Culture*, **15**, Nov. 1949.
(4) 'On certain probability distributions arising from points on a line' (under preparation).
(5) 'Probability distributions of points on a lattice' (under preparation).

Final Report.

Name of Research Fellow .. Mr. Y. Sundar Rao.

Subject of Research .. Cytotaxonomy of Helobiales.

(October 18th, 1948—October 17th, 1950.)

Helobiales is a group of great phylogenetic importance. A karyological study from the point of view of its phylogeny is the object of the present investigation. A preliminary survey of the chromosome numbers revealed that the group is specially interesting from the point of view of chromosome races within the species. With a view to evaluate their taxonomic significance intensive study of their karyotypes was undertaken and a correlation was sought between their morphological features and their degree of ploidy. Special emphasis was also laid on the geographic distribution of such races. The important results achieved during the years under report are summarised below. The details mentioned in the first annual report are omitted here.

Butomaceae.

The karyotypes of *Tenagocharis latifolia* ($2n = 14$) and *Hydrocleis nymphoides* ($2n = 16$) show morphologically similar chromosomes, indicating common ancestry. The change in the haploid number from 7 to 8 occurred probably through fragmentation. *Butomus umbellatus* ($2n = 26$) had probably amphidiploid origin from 6 and 7 chromosomal ancestors.

Alismataceae.

In this family the haploid chromosome numbers are: *Alisma Plantagoaquatica* = 7; *Echinodorus ranunculoides* = 8; *E. radicans* = 11; *Sagittaria sagittifolia* = 11. It is clear that aneuploidy determines the intergeneric relationships within the family. Studies on the chromosome morphology go to show that such aneuploid changes are associated with the increase in the terminally constricted chromosomes and that fragmentation is responsible for it.

Aneuploid chromosome races are also common in certain species of the family like *Alisma Plantago-aquatica*. But no deviating chromosome number could be found in a group of plants collected at Hoshiarpur, while such races are common in Europe. Though the plants in question do not show any deviation in the chromosome number, yet different plants show differences in the length of the satellites. Majority of the plants are characterised by a pair of chromosomes with short satellites, a few with long satellites and very few with both long and short satellites. Obviously, the third category represents the hybrids of the other two types of plants. The leaves of the plants studied are broadly ovate, deeply cordate at the base, thick, coriaceous with undulate margins.

Hydrocharitaceae.

One of the predominant cytological features of the family is polyploidy (both auto- and allo-), which attained different degrees in different genera. In *Hydrilla verticillata* diploids and triploids with a basic number 8 were reported; in *Elodia* diploid, triploid and hexaploid species and races occur. Polyploidy reached an extreme expression in *Ottelia alismoides*, which is now known to occur in diploid, tetraploid and hexaploid chromosome races with a basic number 11. Evidence gathered from chromosome morphology and chromosome pairing during meiosis indicates that allopolyploidy is responsible for the evolution of the races.

In certain morphological features, diploids present certain differences when compared with the polyploids. For example, almost all diploids are a little shorter in stature and have slightly smaller leaves and flowers than those of the hexaploids though the size relations are not always absolute. Most of the diploid forms have broadly ovate leaves with *less cordate* or almost straight base while those of the hexaploids are variable in shape with *highly cordate* base. The diploids have white flowers and those of the hexaploids are either white or pink. Comparatively, the pollen grains of the diploids are invariably smaller than those of the polyploids.

More interesting is the geographic distribution of the chromosome races in India and elsewhere. The facts gathered from chromosome numbers of plants collected from different regions in India and the study of the morphological features of the herbarium specimens gathered from the whole range of distribution led to the conclusion that *O. alismoides* originated in such tropical regions like S. India and Malaya (Sundar Rao, *Curr. Sci.*, **20**, 72, 1951).

The present cytological investigation supports the amalgamation of the unisexual *Boottia* with the bisexual *Ottelia*, as the former has also the same chromosome numbers and shows similar chromosome morphology.

Najadaceae.

Najas minor All., var. *spinosa* Rendle ($2n = 24$) is a tetraploid with a basic number 6. The karyotype has three pairs of long, three pairs of medium-sized and six pairs of short chromosomes.

Final Report.

Name of Research Fellow .. Dr. S. VedaRaman.

Subject of Research .. Adsorption of gases by industrially important catalysts and kinetics of gas reaction.

(September 1, 1948—August 31, 1950.)

This report deals with a number of adsorption studies at various temperatures and over a whole range of pressure varying from one to fifty atmospheres on three synthetic methanol catalysts and the adsorption of hydrogen on a promoted nickel catalyst (employed in the Fischer-Tropsch synthesis) progressively poisoned with varying amounts of carbon monoxide. The catalysts have been designated as 'A', 'B', 'C' and 'D' and their exact compositions have been given.

On catalysts A and B, volumetric measurements of the adsorption of hydrogen and carbon monoxide at pressures ranging from 10 to 70 cm. on A and from 15 to 50 atmospheres on A and B have been done. Low pressure measurements of hydrogen adsorption on catalyst A have

revealed that the highest adsorption is taking place at about 204° C. in agreement with the previous observations of Taylor and Strother for their sample of zinc chromate. In contrast to catalyst A, hydrogen adsorption on catalyst B increases continuously with increase of temperature up to the maximum temperature investigated. Catalyst B shows greater adsorptive capacity for hydrogen than catalyst A.

A new static volumetric technique has been developed for the adsorption of gases by solids at elevated pressures. Employing this technique the adsorption of hydrogen and carbon monoxide has been studied on catalysts A and B. Adsorption isotherms have been studied at eight different temperatures. It is pointed out that no previous work on the adsorption of hydrogen or carbon monoxide at elevated pressures has been done on methanol catalysts. In conformity with the low pressure measurements a maximum for hydrogen adsorption is observed at 204° C. for catalyst A. For the first time the distinctive occurrence of a second maximum for hydrogen adsorption on catalyst A at about 300° C. and at elevated pressures has been observed. For catalyst B, in agreement with low pressure measurements, the adsorption of hydrogen increases continuously with increase of temperature.

In contrast with the results of Taylor and Kistiakowsky for their catalyst $ZnO\text{-}Cr_2O_3$ who found that both the adsorption of hydrogen and carbon monoxide was pronounced at very low pressures and rapidly reached saturation capacity independent of further pressure increase, the observations made here on catalyst A point to adsorption increasing sharply with increase of pressure as revealed by the measurements at elevated pressures. The results obtained with catalyst B in this respect contrast with those of catalyst A in that the former attains saturation very quickly (so quickly indeed that kinetic measurements could not be done on it) and that its adsorptive capacity is not very much affected by increase of pressure. A comparison of the low pressure values of hydrogen adsorption on catalyst C with those of B, has clearly brought out the importance of chromia for increased hydrogen adsorption and also the loss in activity when chromia is replaced by titania.

Carbon monoxide adsorption at low pressures, on the three methanol catalysts has revealed distinctly two maxima one occurring at about 52° and the other at about 178° C. In other words, two types of activated adsorption of carbon monoxide take place on all three of them. Heats of adsorption calculated definitely point to the occurrence of activated adsorption even at 52° C.

As in the case of hydrogen, the adsorptive capacity of catalyst B for carbon monoxide is greater than that of A and C. Experiments at elevated pressures indicate increased adsorption of carbon monoxide with increase of pressure on both A and B. As in the case of hydrogen, carbon monoxide adsorption on catalyst A, increases sharply with increase of pressure, while on catalyst B the effect of pressure is not marked. A comparison of the low pressure data of B and C obtained with carbon monoxide reveals that chromia is a good adsorbent for carbon monoxide also.

All the three methanol catalysts show a slightly better adsorptive capacity for hydrogen than carbon monoxide. An explanation for the superior catalytic activity of B over that of A and A over that of C is provided by adsorption studies on these catalysts. Addition of copper, ceria and thoria to the binary combination zinc and chromium produces a catalyst which is considerably more active than the binary one. It is also seen that chromia is far superior to titania as a promoter.

The differential heats of adsorption calculated from the adsorption data are found to be of the same order as those generally obtained for activated adsorption. The values vary with the amount of gas adsorbed, that is, heats decrease with increase in surface coverage, thereby indicating a pronounced heterogeneity of the catalyst surface.

Velocity of adsorption of hydrogen on catalysts A and C and of carbon monoxide on catalyst A have been determined at various temperatures and pressures. The activation energies of hydrogen adsorption and those of carbon monoxide adsorption calculated from the velocity data have revealed in conformity with the results of previous workers, that the energies increase with increase in the amount of gas adsorbed. The data reveal that the surfaces of the catalysts are composite, with areas have characteristic activation energies ranging from low values to very high values. The results also reveal that the comparatively poor adsorptive capacity of catalyst C and the decrease in its catalytic activity are due to the incorporation of titania. The incorporation of chromia, copper, ceria and thoria to zinc oxide, on the other hand, increases the amount of activated adsorption and decreases the activation energy.

The new experimental technique developed by Taylor and Liang has been employed for determining isobars of adsorption of hydrogen on catalyst A at various temperatures. The experiments reveal desorption of chemisorbed hydrogen from the catalyst surface on raising the temperature through certain temperature ranges at constant pressure. The desorption is then followed by further chemisorption of the gas.

Another feature of the present work is that investigations have been done on promoted nickel and cobalt catalysts poisoned progressively with various amounts of carbon monoxide. This is the first time that such an investigation has been undertaken. It has been found that minute doses of the poison considerably enhance the adsorption of hydrogen, whereas greater amounts suppress it over the entire pressure range studied. An explanation of the phenomena has also been given.

(2)

IMPERIAL CHEMICAL INDUSTRIES (INDIA) RESEARCH FELLOWSHIP.

ANNUAL REPORT.

Name of Research Fellow .. Dr. C. Ramasastry.
Subject of Research .. Spectroscopy.

(June 19, 1949—June 18, 1950.)

The research programme was commenced in June 1949 and comprises of the spectroscopic study of diatomic and polyatomic molecules.

The results of the investigations of the research fellow on the diatomic zinc bromide molecule resolved the anomaly as regards its vibrational constants.

The near ultraviolet absorption spectra of chloro-phenols have also been studied by the research fellow from the point of view of electronic structure and theory of valence. This topic of study assumed a new importance in the light of the recent investigations on the aromatic series of organic molecules consisting of benzene and its derivatives. The research fellow has obtained and analysed the characteristic absorption spectrum of a di-substituted benzene molecule, ortho-chloro-phenol. The results are of importance for the correlation of chemical structure with the electronic absorption of polyatomic molecules.

Preliminary investigations on a triatomic molecule, carbondisulphide have also been completed

Name of Research Fellow .. Dr. A. K. Chakravorti.
Subject of Research .. Cytogenetics of some common fruit trees of India and the application of colchicine to raise improved types.

(March 1, 1950—February 28, 1951.)

Cytogenetical investigation of the following fruit trees were in progress:—

(1) *Anona squamosa*, (2) *A. reticulata*, (3) *Physalis minima*, (4) *P. peruviana*, (5) *Flacourtia sepieria*, (6) *F. ramontchi* (7) *Carica papaya*, (8) *Eugenia uniflora*, (9) *E. malaccensis*, (10) *E. javanica*, (11) *E. jambos*, (12) *E. jambolana*, (13) *Citrus decumana*, (14) *C. medica*, (15) *Psidium guayava*, (16) *Nephelium litchi*, (17) *N. longana* (18) *Achras sapota*, (19) *Zizyphus jujuba*, (20) *Spondias anacardium*, (21) *Grewia subinequalis*.

The behaviour of the chromosomes during meiosis in the P.M.C.s has been examined in detail in *Carica papaya*, *Anona squamosa*, *A. reticulata*, *Eugenia uniflora*, *E. malaccensis*, *E. javanica*, *Physalis minima*, *P. peruviana* (both naturally occurring diploid and tetraploid, and colchicine-octoploid forms), *Citrus decumana*, *Nephelium litchi* and *N. longana*.

Pairing of the chromosomes has been found to be normal and regular in all the above species, excepting *Eugenia javanica* and colchicine-octoploid *Physalis peruviana*. Very rarely, however, slight irregularity has been noticed in some of them. In *Eugenia malaccensis*, for example, a diakinetic nucleus has been found to contain 8 bivalents and 2 trivalents instead of 11 bivalents; and in *Anona squamosa* the nucleus of the P.M.C. has rarely been found to restitute during division I. In addition occasional laggards were observed during anaphase I in almost all the species examined.

Pairing of the chromosomes were found to be weak in *Carica papaya*, *Anona squamosa*, *A. reticulata* and *Citrus decumana*, the chiasma frequencies per bivalent in them being 1·35, 1·36, 1·41 and 1·40 respectively.

Meiosis is irregular in *E. javanica* and colchicine-octoploid *Physalis peruviana* due to their polyploid nature. In *E. javanica* all types of chromosome pairing, from univalent to quadrivalent, characteristic of tetraploid plants, have been found. The percentages of univalents, trivalents and quadrivalents are, however, low. This feature suggests that the species is in all probability an allotetraploid.

Owing to their auto-polyploid nature, the colchicine-octoploids of *P. peruviana* show irregular pairing of their chromosomes. Various kinds of chromosome associations, from univalents to hexavalents, could be seen. Associations higher than hexavalents though expected were never observed. Among quadrivalents, true rings characteristic of non-homologous interchanges, were found to occur. There is a high percentage of pollen sterility, 40·6% of the grains being abortive.

Distinct evidence of secondary association between bivalents during metaphase I has been obtained in *Carica papaya*, *Citrus decumana*, *Nephelium litchi* and *N. longana*.. The maximum association of the 9 bivalents of *Carica papaya* is 1(3)+3(2) and that of *Citrus decumana* is 3(3). From this it appears that the basic number of *C. papaya* is 4 and that of *C. decumana* is 3.

The nature of the secondary pairing of the bivalents in the two species of *Nephelium* referred to above has not yet been statistically analysed.

A study of the meiosis in other species and a karyotype analysis of all the species are in progress.

Application of colchicine to *Carica papaya* and *Physalis peruviana* (4*n*) was met with success, producing their corresponding tetraploid forms. The growing tips of the seedlings (2" to 2½" in height) of these two species were covered with cotton pads soaked in 0·25% colchicine solution for 24 hours. The pads were then removed and the growing tips were washed with distilled water with a soft brush. Out of the 50 treated seedlings of *C. papaya* only 5 appeared to have given positive results, and out of 4 naturally occurring tetraploid seedlings of *P. peruviana* 3 became octoploid.

The tetraploid *C. papaya* has not yet flowered. Doubling of the chromosomes of *P. peruviana* has brought about general giganticism of the different organs of the treated plants, especially in the flowers and the fruits.

Name of Research Fellow .. Mr. T. V. R. Pillay.

Subject of Research .. Culture of Grey Mullets.

(December 1, 1949—November 30, 1950.)

Studies on the biology of the Grey Mullet, *Mugil tade* Forsk. and mullet culture practices in *bheris* near Calcutta were continued during the year. Samplings and field observations were conducted in three selected centres in Bengal, *viz.*, Junput (sea-coast), Port Canning (Matlah estuary) and Ghutiari Sharif (enclosed farm).

Systematics.—The intraspecific variations in *M. tade* were studied and a complete description of the species was prepared. The relationship between the different body measurements and the total length of the fish, as also the rate at which the different parts of the body grow in relation to the total length was determined statistically. The analyses of morphometric data of samples of *M. tade* collected from the seacoast at Junput and the estuary at Port Canning during different seasons of the year, showed that there is no significant differences between the stocks in these two areas. Statistically significant differences were, however, observed in the morphometric characters of specimens reared in the enclosed farm.

Fishery.—Mullet fishing methods and the composition of catches were studied from Junput and Port Canning. The results of this investigation as also the study of systematics have been incorporated in a paper entitled 'The Grey Mullet, *Mugil tade* Forsk. and its fishery in Bengal'. The analyses of catches from the farm shows that the fish is seldom allowed to grow to a large size.

Food and Feeding Habits.—Studies on the food of *M. tade* in different environments during different seasons of the year, have been concluded. Field observations and aquarium experiments were also conducted to ascertain its feeding habits. All the available data shows that it feeds at the bottom on the iliotrophic layer. Early juveniles have been observed to feed on the surface or an attached algae. A preliminary note on the food and feeding adaptations of the fish was published in *Sci. & Cult.*, **16**, 261-262. A detailed investigation of the morphology of the alimentary canal was made with a view to correlate it with its food and feeding habits. Work on the histology of the alimentary tract was started.

Length-weight relationship and Condition factor.—The weight of *M. tade* was found to increase as an exponential function of its length. The equation for the curve is $W = 0{\cdot}03337\ L^{2{\cdot}6198}$, where W = wt. in grammes and L = the total length in cm. The condition factor decreases with increase in length of the fish. The data collected so far indicated that the condition factor is at its minimum during the spawning season. More data is being collected to establish this and to ascertain the size at first maturity.

Association with Zoothamnium.—A new species of *Zoothamnium*, a colonial protozoan, found growing in association with *M. tade* in a fresh-water tank was studied in detail and a paper entitled 'On a new species of *Zoothamnium* (Vorticellid—Protozoa) from the Grey Mullet, *Mugil tade* Forsk.' prepared in collaboration with Mr. H. Khajuria is now under publication in the Records of the Indian Museum.

Salinity tolerance.—Laboratory experiments have shown that salinities higher than 35‰ are harmful to the well-being of mullets. However, if the rise is only gradual, about 25‰ of the fish are able to 'acclimatise' to even as high a salinity as 60‰.

Predators.—It has been observed that *Lates calcarifer* and *Eleutheronema tetradactylum* are the main predators of mullets in brackish water farms in Bengal. Field observations and experiments failed to substantiate the general belief that the common pond frog is detrimental to mullet fry in fresh-water ponds.

Name of Research Fellow .. **Dr. S. N. Ghosh.**
Subject of Research .. **Radiation of Earth's Upper Atmosphere.**

(March 1, 1949—August 22, 1950.)

Work for the construction of the apparatus for the study of the strong line λ 10444 of the night sky light is continued and is nearing completion. The apparatus consists mainly of a Thermistor Bolometer V649 by Western Electric Co., on which radiation from the luminescence of the night sky is focussed by a reflector. The output of the bolometer is amplified, rectified and finally drives a penrecorder.

Power Pack

The power supply utilised a standard power pack transformer producing about 400 volts d.c. at the rectifier cathode. It is followed by a voltage stabiliser utilising three 25L6 tubes and a 6SJ7 amplifying tubes. The reference voltage of stabiliser is 45 volt dry battery.

The power pack supplies the H.T. power and the cathode heating power of the amplifier as well. Smoothed d.c. is necessary for the heaters of the amplifier tubes, as otherwise, they pick up considerable amount of ripples from the heater line.

Reflector

To measure the radiation from the night sky it has been estimated that the thermistor has to deal with signals of the order of 10^{-11} volts. An amplifier cannot possibly utilise such weak signals, radiation from the night sky light is condensed by reflector.

Amplifier

In this field of instrumentation, high gain amplifiers capable of handling extremely low input levels are required. Following general practice an a.c. amplifier is used instead of a d.c. type. For, a d.c. amplifier cannot be prepared which has a spontaneous drift less than 10 millivolt, as such, a d.c. amplifier cannot profitably be utilised for the input signal less than 10 millivolt. As the voltages that will be obtained from the thermistor even after condensing radiation on it are extremely small, one has to construct an a.c. amplifier to obtain the required amplification. The a.c. signal is obtained thus. The incoming signal is interrupted by a rotating mechanical shutter whereupon an interrupted signal is produced by the thermistor. This is possible because the time constant of the thermistor is small, of the order of 0·005 sec.

Choice of the operating frequency of the amplifier

The a.c. amplifier must be of exceeding narrow bandwidth as otherwise such weak signal cannot be distinguished in presence of the noise. In order to reduce the bandwidth, it is desirable to operate the amplifier at as low a frequency as possible. But too low a frequency makes the design of the apparatus rather complicated. Further, frequency in the neighbourhood of 50 cps. is to be avoided for the presence of ripples from the power line.

From these considerations, the operating frequency of the amplifier was chosen as 37 cps. with a bandwidth of 1 cps. wide.

Preamplifier

It is a two-stage resistance-coupled amplifier operated by a 90 volt dry battery. The receiver flake of the thermistor is placed between grid-earth and the compensator between H.T. and the grid of the input valve. Wire-wound resistances are used in the anode circuit as the resistance noise of the carbon resistors are found to be considerable.

The preamplifier chasis must be airtight and contain silica gel dehydrator container. It is completely shielded and provided with a shutter.

Main Amplifier

It contains three resistance-coupled and one transformer-coupled stage. The transformer-coupled stage is a tuned amplifier resonating at 37 cps. It feeds into a diode receiver whose output is applied to a 6J5 cathode follower. The cathode follower drives a penrecorder.

Name of Research Fellow .. Dr. K. K. Reddi.
Subject of Research .. Rôle of antithiamine factor in nutrition.

(June 1, 1949—November 27, 1950.)

In vivo STUDIES ON 'ANTI-THIAMINE FACTOR' IN MUSTARD (*Brassica juncea*).

INTRODUCTION.

The period under review has been devoted to the study of the influence of the anti-thiamine factor, isolated from mustard, on the availability of added thiamine to rats. The direct study on rats is of more practical value in assessing the harmful nature of the factor.

EXPERIMENTAL.

Procedure.—Twenty-four young albino rats, 4 weeks old, weighing 32–45 gms. and of known nutritional history were used as experimental animals. These were placed in individual cages provided with raised wide mesh bottoms, to prevent the animals to have access to excreta. They were fed on basal diet, (vitamin B_1 free diet), prepared according to Evans and Lepkovsky, for seven days to deplete the animals of their vitamin B_1 reserves. At the end of this period they were assembled into four groups, each group having six animals.

Group 1.—Basal diet +5 micrograms thiamine hydrochloride.
Group 2.—Basal diet +5 micrograms thiamine hydrochloride +anti-thiamine factor (vitamin and A.T.F. were incubated for 30 minutes at 37°C.).
Group 3.—Basal diet +5 micrograms thiamine hydrochloride +one c.c. A.T.F. (vitamin and A.T.F. were given separately).
Group 4.—Basal diet only.

10 grams of basal diet per day per rat was given. The vitamin B_1 was delivered through pipette into mouth. Before giving the regular diet the rats in group 2 were given a mixture of vitamin B_1 and A.T.F. in small cups with a pinch of sugar. Rats in group 3 received 1 c.c. of A.T.F. After it was licked completely 5 micrograms of thiamine hydrochloride was given through pipette into mouth. The observations of body-weight were made once in 5 days.

Rats in group 1, receiving 5 micrograms of vitamin B_1 steadily gained in weight, thereby indicating that the amount of vitamin B_1 given is quite sufficient for normal growth.

The rats in group 2 receiving a mixture of 5 micrograms of vitamin B_1 and A.T.F. were also healthy and steadily gained in weight.

Rats in group 3 receiving vitamin B_1 and A.T.F. separately were also healthy and gained in weight.

Rats in group 4 receiving basal diet (control group) lost weight gradually and the food in-take has also fallen down. Severe symptoms of vitamin B_1 deficiency were noticed after 4 weeks.

From the observations it is clear, that the action of this factor is entirely different from that isolated from the fresh-water mussel. In the latter case, it brings about the hydrolytic cleavage of the added vitamin B_1 and thus renders it ineffective biologically. In the case of the factor from mustard, even though the *in vitro* experiments showed low recovery of added thiamine, the *in vivo* experiments show that the factor is quite harmless. This experiment shows that the factor does not bring about fission, but it may somehow combine with vitamin B_1 and thus prevent it from conversion into thiochrome.

ON EQUATION OF STATE OF REAL GASES.

By M. DUTTA, *Khaira Laboratory of Physics, University College of Science and Technology, Calcutta.*

(Communicated by Prof. S. N. Bose, F.N.I.)

(Received May 2; read August 3, 1951.)

1. INTRODUCTION.

In several previous papers [Dutta, I, (1947), II, (1948), III and IV, (1951)], by applying a new statistical method of calculation, the general behaviour of real gases have been investigated. As in the usual treatment the peculiarities of a real gas as distinguished from the ideal gas have been attributed to the finite volume of the molecules and to the effects of fields of forces, e.g., of cohesion, etc. A distribution function has been constructed by considering the distributions of the representative points of the molecules in the configurational and momenta spaces separately. In the configurational space a concept of exclusion has been introduced by assuming this space to be made up of cells (of exclusion) each of volume b which can remain either vacant or be filled by one molecule only. This yields the partial thermodynamic probability corresponding to the configurational space. The momenta space is similarly divided to cells, each of volume $\frac{h^3}{b}$, and the corresponding partial thermodynamic probability has been written down in the usual way. The product of these two partial thermodynamic probabilities is taken as the thermodynamic probability of the assembly constituting the real gas under study.

In the present paper the Planck-Saha-Bose equation of state has been worked out for Van der Waal's fields of forces. The result has been made more accurate by taking into consideration the overlapping of the volumes of exclusion by a method similar to Boltzmann's. Further improvement has been sought to be introduced by following a somewhat more rigorous method of calculation. The results of the usual theory are obtained similar in form but with slightly altered coefficient.

2. DESCRIPTION OF THE ASSEMBLY.

The assembly under consideration consists of N non-dissociating and non-associating molecules, each commanding a volume of exclusion of magnitude 'b'. The assembly is enclosed within a volume V.

Now, the effect of cohesion between molecules manifests itself as the formation of a very thin surface layer of potential energy slightly greater than that of the interior. Let the interior be of volume V_1, and of potential energy w_1, and the surface layer of volume V_2, and of potential energy w_2. Now $V_2 << V_1$, $w_1 < w_2$.

After this, the layer will be divided into cells of volume 'b' as usual. It is assumed that $b << V_1, V_2$. Let N_1, N_2 be numbers of molecules in the interior, and in the surface-layer respectively in any complexion. Let a_i represent the number of molecules with energy ϵ_i.

3. Calculations.

It has been shown that, by following the arguments set forth in section 1, the thermodynamic probability of an assembly constituting a real gas can be written as

$$W = \frac{\left(\frac{V_1}{b}\right)!}{N_1!\left(\frac{V_1}{b}-N_1\right)!}\cdot\frac{\left(\frac{V_2}{b}\right)!}{N_2!\left(\frac{V_2}{b}-N_2\right)!}\cdot\frac{N!}{\pi a_i!} \qquad \ldots\ldots\ldots\ldots \quad (1)$$

As shown in a previous paper, (Dutta, II, 1948), we have the following:

$$\left.\begin{aligned} N_1 &= \frac{V_1}{b}e^{-\nu-\frac{w_1}{kT}},\\ N_2 &= \frac{V_2}{b}e^{-\nu-\frac{w_2}{kT}},\\ a_i &= e^{-\lambda-\frac{\epsilon_i}{kT}}, \end{aligned}\right\} \qquad \ldots\ldots\ldots\ldots \quad (2)$$

where

$$\left.\begin{aligned} \lambda &= \log\left\{\frac{1}{N}\frac{b}{h^3}(2\pi mkT)^{\frac{3}{2}}\right\}\\ \text{and}\qquad \nu &= \log\left\{\frac{V_1e^{-\frac{w_1}{kT}}+V_2e^{-\frac{w_2}{kT}}}{Nb}\right\} \end{aligned}\right\} \qquad \ldots\ldots\ldots\ldots \quad (3)$$

As in the same paper, the following expressions for important thermodynamic functions are also easily obtained.

$$\begin{aligned} S = K\Bigg[&-\left(\frac{V_1}{b}\right)\left(1-\frac{Nbe^{-\frac{w_1}{kT}}}{V_1e^{-\frac{w_1}{kT}}+V_2e^{-\frac{w_2}{kT}}}\right)\log\left(1-\frac{Nbe^{-\frac{w_1}{kT}}}{V_1e^{-\frac{w_1}{kT}}+V_2e^{-\frac{w_2}{kT}}}\right)\\ &-\left(\frac{V_2}{b}\right)\left(1-\frac{Nbe^{-\frac{w_2}{kT}}}{V_1e^{-\frac{w_1}{kT}}+V_2e^{-\frac{w_2}{kT}}}\right)\log\left(1-\frac{Nbe^{-\frac{w_2}{kT}}}{V_1e^{-\frac{w_1}{kT}}+V_2e^{-\frac{w_2}{kT}}}\right)\\ &+N\lambda+N\nu+\frac{E}{kT}+N\log N\Bigg] \qquad \ldots\ldots\ldots\ldots \quad (4) \end{aligned}$$

and,

$$\begin{aligned} \psi = K\Bigg[&-\left(\frac{V-V_2}{b}\right)\left\{1-\frac{Nb}{V-V_2\left(1-e^{-\frac{w}{kT}}\right)}\right\}\log\left\{1-\frac{Nb}{V-V_2\left(1-e^{-\frac{w}{kT}}\right)}\right\}\\ &-\left(\frac{V_2}{b}\right)\left\{1-\frac{Nbe^{-\frac{w}{kT}}}{V-V_2\left(1-e^{-\frac{w}{kT}}\right)}\right\}\log\left\{1-\frac{Nbe^{-\frac{w}{kT}}}{V-V_2\left(1-e^{-\frac{w}{kT}}\right)}\right\}\\ &+N\log\left\{1+\frac{V_2}{V}\left(1-e^{-\frac{w}{kT}}\right)\right\}\\ &-N\frac{w_1}{kT}+N\log\left\{\frac{1}{N}\frac{(2\pi mkT)^{\frac{3}{2}}}{h^3}\right\}\Bigg] \qquad \ldots\ldots\ldots\ldots \quad (5) \end{aligned}$$

where

$$w = w_2 - w_1. \qquad \ldots \qquad (6)$$

Now, if the field be assumed to be weak and short-ranged (which is generally taken to be true for Van der Waal's field), then $\frac{V_2}{V}$ and w are small. So the expressions for thermodynamic functions can be expanded in a power series of $\frac{V_2}{V}$ and $\left(1-e^{-\frac{w}{kT}}\right)$, and terms involving powers of $\frac{V_2}{V}$ and $\left(1-e^{-\frac{w}{kT}}\right)$ higher than the first may be neglected.

Then,

$$\psi = K\left[-\left(\frac{V}{b}\right)\left(1-\frac{Nb}{V}\right)\log\left(1-\frac{Nb}{V}\right)+N\log V + N\frac{V_2}{V}\left(1-e^{-\frac{w}{kT}}\right)-N\frac{w_1}{kT}+N\log\left\{\frac{1}{N}\frac{(2\pi mkT)^{\frac{3}{2}}}{h^3}\right\}\right]. \qquad \ldots \qquad (7)$$

Now, from the well-known thermodynamic relation,

$$p = T\left(\frac{\partial\psi}{\partial V}\right)_T$$

we have

$$p = NkT\left[-\frac{1}{Nb}\log\left(1-\frac{Nb}{V}\right)-\frac{1}{V}\left\{\left(\frac{\partial V_2}{\partial V}\right)_T-\frac{V_2}{V}\right\}\left(1-e^{-\frac{w}{kT}}\right) - \frac{V_2}{V}e^{-\frac{w}{kT}}\frac{1}{kT}\left(\frac{\partial w}{\partial V}\right)_T-\frac{1}{kT}\left(\frac{\partial w_1}{\partial V}\right)_T\right] \qquad \ldots \qquad (8)$$

or

$$p+\frac{\alpha}{V^2} = -\frac{kT}{b}\log\left(1-\frac{Nb}{V}\right) \qquad \ldots \qquad (8a)$$

where,

$$\alpha = NkT\left[\left\{V\left(\frac{\partial V_2}{\partial V}\right)_T - V_2\right\}\left(1-e^{-\frac{w}{kT}}\right)+\frac{V_2}{kT}e^{-\frac{w}{kT}}\cdot V\cdot\left(\frac{\partial w}{\partial V}\right)_T + \frac{1}{kT}\left(\frac{\partial w_1}{\partial V}\right)_T\right]. \qquad \ldots \qquad (9)$$

It should be noted that the expression for α, obtained here, is same as that for α in a previous paper (Dutta, II, 1948), and it is shown there that α is proportional to N^2. So, $\frac{\alpha}{V^2}$ is the usual Van der Waal's correction for pressure. The equation (8*a*) is the Planck-Saha-Bose equation of state for real gas (Planck, 1908; Saha and Bose, 1918).

4. A MORE ACCURATE SPECIFICATION OF *b*.

Now, '*b*', the volume of exclusion of each molecule means the volume which the centre of any molecule commands exclusively of any other. In papers referred to the above *b* has been taken to be independent of the volume and the temperature and ultimately taken to be equal to the volume of a sphere about the centre of a molecule with a radius equal to the diameter of a molecule. This sphere will be

referred as the covering sphere (Deckungsphären) of a molecule. But a little reflection will show that it is only a very rough approximation of the reality. It is a fact that the centre of a molecule of finite dimension cannot come within the covering sphere of the other, but it can come to such a close position that it is on the surface of a covering sphere of the other. Now, when the centre of one molecule comes sufficiently near to the surface of the covering sphere of the other, portions of their covering spheres will overlap. So, 'b', which represents the average volume of covering sphere of one molecule left exclusively for it, cannot be equal to that of the covering sphere. If the volume of the covering sphere be denoted by b_0 then b the average value exclusively commanded by each molecule may plausibly be written as

$$b = b_0\left\{1 - f\left(\frac{N}{V}, T, b_0\right)\right\}. \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (10)$$

Obviously, the volume of each cell of configurational space in present calculations of previous sections should be taken as this b.

It will be assumed that the function f can approximately be represented as $\frac{Nb_0}{V}\gamma$, so that the above relation may be approximately replaced by

$$b = b_0\left(1 - \gamma\frac{Nb_0}{V}\right). \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (11)$$

Here, γ has been introduced for taking into account the two factors, i.e. that the portion of the volume V, really occupied by matter is not Nb_0, but something less than this, and secondly, that some portions of this cannot really be occupied due to the geometry of shape playing a rôle in packing.

5. Calculations with b.

Now, for simplicity, we shall first consider the case in which the field is absent. The exclusion to the cases of Van der Waal's field of force or of the like appears to be easy and straightforward. Then, in absence of any field of force, it yields

$$\psi = k\left[-\left(\frac{V}{b}\right)\left(1-\frac{Nb}{V}\right)\log\left(1-\frac{Nb}{V}\right)+N\log V+N\log\left\{\frac{1}{N}\frac{(2\pi mkT)^{\frac{3}{2}}}{h^3}\right\}\right]$$

$$= Nk\left[\log V - \frac{1}{2}\left(\frac{Nb}{V}\right)-\frac{1}{6}\left(\frac{Nb}{V}\right)^2-\frac{1}{12}\left(\frac{Nb}{V}\right)^3-\ldots.\right.$$

$$\left.+\log\left\{\frac{1}{N}\frac{(2\pi mkT)^{\frac{3}{2}}}{h^3}\right)\right]. \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (12)$$

Retaining up to $\left(\frac{Nb_0}{V}\right)^2$ we have,

$$\psi = Nk\left[\log V - \frac{1}{2}\frac{Nb_0}{N} - \frac{1-3\gamma}{6}\left(\frac{Nb_0}{V}\right)^2+1+\log\left\{\frac{1}{N}\frac{(2\pi mkT)^{\frac{3}{2}}}{h^3}\right\}\right] \quad \ldots \quad (13)$$

and

$$p = T\left(\frac{\partial\psi}{\partial V}\right)_T$$

$$= \frac{NkT}{V}\left[1+\frac{(\frac{1}{2}Nb_0)}{V}+4\frac{1-3\gamma}{3}\frac{(\frac{1}{2}Nb_0)^2}{V^2}\right]. \quad \ldots \quad \ldots \quad (14)$$

6. Evaluation of γ.

To be convinced of the potentiality of the present method, γ has been at first calculated on using the method referred above, and on following the basic Boltzmann's ideas of overlapping of covering spheres. (Boltzmann, 1923.) Of course, slight modifications are introduced to fit it with the formalism of the present scheme. The calculation yields the same value for the second virial coefficient as obtained by Boltzmann. A close scrutiny of the method shows that the method is open to serious objection. In a later section, we have given a new method for calculation of γ, which, though approximate, is free from objectionable features just mentioned.

To evaluate γ up to first approximation, it will be assumed that the assembly is of such a density that the frequencies of encounters (better, overlapping) of higher order than the second is negligibly small, and their contributions will be neglected here. Only, simultaneously overlapping of covering spheres of a pair of molecule will be considered here. The extension of present discussions of those cases where simultaneous overlapping of covering spheres of higher order appears to be straightforward and will be developed hereafter.

Evidently, there will be an overlapping of covering spheres where the distance between the centres of any two molecules is less than the diameter $2d$, where d represents the diameter of a molecule. Let the attention be focussed upon the centre of a particular molecule, and let the centre of any other molecule come to a distance x from that of the molecule, where $d < x < 2d$. Now the portion of the volume of any of the covering spheres which is left exclusively to the molecule under consideration is the volume of the larger segment of the covering sphere cut up by the common plane-section while the remaining smaller segment is to be taken as the volume lost due to overlapping. The portion of the volume of the covering sphere of the molecule under consideration, overlapped by other, can be written after Boltzmann, as

$$K_n = \pi \int_{\frac{x}{2}}^{d} (d^2 - y^2)\, dy = \pi\left(\frac{2d^3}{3} - \frac{d^2x}{2} + \frac{x^3}{4}\right) \quad \ldots \quad (15)$$

Then, the frequency of overlapping under the conditions that the centre of one molecule is at distance $(x, x+dx)$ from the other may be taken as

$$p_x = \frac{4\pi x^2\, dx}{V} \cdot n. \quad \ldots \quad (16)$$

Let us assume that with the centre of the colliding molecule lying within distance $(x, x+dx)$ from the centre of found molecules it is geometrically possible for only n molecules to participate in overlapping with a given single molecule. We shall leave to n the theoretical possibility of varying from 0 to N.

The frequency of overlapping in all layers between x and $x+dx$ round all molecules is then

$$dn_x = \frac{4\pi x^2\, dx}{V} n \cdot \frac{n}{2} \quad \ldots \quad (17)$$

since in pairing each molecule is counted twice.

So, the expected value of volume overlapped in the covering spheres of pair of molecules, (when n molecules are participating or having tendency of overlapping), is

$$Z_n = \int 2K_x dn_x = \frac{1}{2}\frac{\pi^2 n^2}{V}\int_d^{2d} 2\left(\frac{8d^3}{3} - 2d^2x + \frac{x^3}{3}\right)x^2\, dx$$

$$= \frac{17}{16}\frac{n^2 b_0^2}{V} = 2n^2 b' \quad \ldots \quad (18)$$

where

$$b' = \frac{17}{32}\frac{b_0^2}{V}. \qquad \ldots \ldots \ldots \ldots \quad (19)$$

Now, in different complexions, different numbers of molecules will participate or will have tendency to participate in overlapping. In different complexions, the number of pair of molecules participating or having tendency to participate varies from 1 to $\frac{N}{2}$. So, to calculate the required value of γ average should be taken amongst all those cases.

Then, average volume, lost in overlapping, per pair, is

$$\bar{Z} = \frac{\sum_1^{\frac{N}{2}} n^2 \cdot 2b'}{\sum_1^{\frac{N}{2}} n} = \frac{\frac{1}{3}\left(\frac{N}{2}\right)^3 \cdot 2b'}{\frac{1}{2}\left(\frac{N}{2}\right)^2} = \frac{1}{3} N \cdot 2b' \text{ (approximately).} \qquad \ldots \ldots \quad (20)$$

Then, average volume, lost in overlapping, per individual, is

$$\gamma \frac{Nb_0^2}{V} = \frac{1}{2} \cdot \frac{1}{3} \cdot N \cdot 2b' = \frac{1}{3} \cdot \frac{17}{32} \frac{Nb_0^2}{V}. \qquad \ldots \ldots \ldots \quad (21)$$

$$\therefore \gamma = \frac{1}{3} \cdot \frac{17}{32} = \frac{17}{96}. \qquad \ldots \ldots \ldots \ldots \quad (22)$$

Then, from equation (13) and (14), it follows that

$$\psi = Nk\left[\log V - \frac{\frac{1}{2}Nb_0}{V} - \frac{5}{16}\frac{(\frac{1}{2}Nb_0)^2}{V^2} + 1 + \log\left\{\frac{1}{N}\frac{(2\pi mkT)^{\frac{3}{2}}}{h^3}\right\}\right] \qquad \ldots \ldots \quad (23)$$

and

$$p = \frac{NkT}{V}\left[1 + \frac{\frac{1}{2}Nb_0}{V} + \frac{5}{8}\frac{(\frac{1}{2}Nb_0)^2}{V^2}\right]$$

$$= \frac{NkT}{V}\left[1 + \frac{\beta}{V} + \frac{5}{8}\frac{\beta^2}{V^2}\right]. \qquad \ldots \ldots \ldots \ldots \quad (24)$$

This equation is same as that which Boltzmann (1923), and others obtained by different methods.

Now, in presence of Van der Waal's field of force, proceeding as in above from equations (7), (8) and (8*a*), this equation becomes

$$p + \frac{\alpha}{V^2} = \frac{NkT}{V}\left[1 + \frac{\beta}{V} + \frac{5}{8}\frac{\beta^2}{V^2}\right]. \qquad \ldots \ldots \ldots \quad (25)$$

Comparison of the method, developed above with the method of Boltzmann.

Before proceeding further, it appears to be necessary and, also, illuminating to analyse the method, developed above, and one of the other well-known methods, which is due to Boltzmann, for considering the effect of overlapping of covering spheres, and to be convinced of similarity and difference between them. To calculate the effect of volume exclusion for covering spheres and of their overlapping, Boltzmann constructed the expression for thermodynamic probability on starting

from the supposition that the volume is initially empty and is then filled by introducing molecules one by one. According to him, the contribution to the expression of the thermodynamic probability by the first molecule entering in the volume is taken to be a factor V, that by the second is taken as $V-b_0$, that by the third as $V-2b_0+Z_2$, that of the fourth is $V-3b_0+Z_3$ and so on, where Z_n has interpretations similar to (18) above. The product of all these factors is taken as the correction for the effect of the volume exclusion together with the overlapping of covering sphêres of molecules.

But, this supposition of the introducing molecules one by one in the volume considered is very artificial, and is not consistent with the formalism of the usual method of Planck and Lorentz based on Boltzmann hypothesis. Now, if the formalism of the usual statistical methods, based on Boltzmann hypothesis, is strictly adhered to then what Boltzmann has done will appear to be equivalent to taking respective consideration of the overlapping of covering spheres of one molecule by no molecule, by one molecule only, by two only and so on. Moreover, as the effects of overlapping by no molecule, by one only, by two only, and so on, are taken to be involved equally in calculations, so the occurrences of overlapping of covering spheres of one molecule by no molecule, by one only by two only, and so on, as it appears, are tacitly assumed to be equally frequent. Now, the method, developed in previous article, are based on these two hypothesis and so is equivalent to that of Boltzmann in principles, and yields same results as it is to be expected.

Criticism of the above and suggestion of a new scheme of calculation.

The methods, developed and discussed in the above, appear to be open mainly to two objections. Firstly, in those methods, overlapping of covering sphere of one molecule by molecules where n is different from N, and varies from 0 to N, has been considered. A little reflection will show that this way of approach is very artificial. As the total number of molecules in volume is always N, and as there are random distributions amongst them in different complexions, so there is no justification for taking n, the number of molecules participating or having tendency to participate in overlapping, different from $N-1$ or N as $1 \ll N$. So, the frequency (or, better probability) of the layer between x and $x+dx$ about the centre of a particular molecule, being occupied, should be taken as

$$dn_x = \frac{4\pi x^2\,dx}{V}\cdot N. \qquad \ldots\ldots\ldots\ldots \quad (26)$$

and, so, the expected value of volume overlapped from the covering sphere of that molecule is to be taken as

$$Z_N = \frac{\pi^2 N}{V}\int_d^{2d}\left(\frac{8d^3}{3}-2\,d^2x+\frac{x^3}{6}\right)x^2\,dx$$

$$= \frac{17}{16}\frac{Nb_0^2}{V} = 2b'' \qquad \ldots\ldots\ldots\ldots \quad (27)$$

where

$$b'' = \frac{17}{32}\frac{N_0 b_0^2}{V}. \qquad \ldots\ldots\ldots\ldots \quad (28)$$

Secondly, in averaging process of $\bar{Z}$ in the above, considerable contribution has been taken even for very improbable occurrences. This is highly objectionable. In this connection it is to be remembered that, in some complexions, there will be no overlapping, in some complexions, there will be overlapping amongst one pair only, in some amongst two only, etc., but the frequencies of occurrence of the complexions

of different types are different, as will be clear from the discussions given below. So proper considerations should be taken for this fact, and the average taking in (20) should be a weighted average. For this, the probability (or frequency) of occurrences of complexions with no overlapping, those with one pair only, etc., should be calculated first.

In forming some ideas about these probabilities of frequencies, as usual, the *a priori* probability of any particle to occur in a volume ΔV will be taken as $\frac{\Delta V}{V}$. So, *a priori* probability of the centre of any molecule occurring within a cell in the configurational space is to be taken as b/V. The volume of a sphere with radius equal to the diameter of the covering sphere is $8b$. There is no overlapping of covering spheres of a particular molecule, if centre of no other molecule come within a distance d and $2d$ from the centre of the particular molecule. In the present formalism of distribution of representative points of molecules in cells of configurational space this fact can be roughly expressed as there is no overlapping of covering sphere of a particular molecule, if 7 cells, contiguous to cell occupied by the representative point of each molecule, remain vacant. For this calculation, no distinction (which is expected to give higher order terms) will be made between b and b_0. Thus, the number of arrangements in configurational space, without any overlapping of covering sphere is

$$\frac{V}{b}\left(\frac{V-8b}{b}\right)\cdots\left(\frac{V-\overline{N-1}\,8b}{b}\right)=\frac{8^N\left(\frac{V}{8b}\right)!}{N!\left(\frac{V}{8b}-N\right)!}.$$

As molecules are perfectly similar such that permutations amongst themselves will give no new arrangement, so the number of complexions is

$$\frac{8^N\left(\frac{V}{8b}\right)!}{N!\left(\frac{V}{8b}-N\right)!}.$$

So, the probability of occurrences of no overlapping is

$$\frac{\left(\frac{V}{8b}\right)!\,8^N}{N!\left(\frac{V}{8b}-N\right)!}\cdot\left(\frac{b}{V}\right)^N\cong\frac{\left(\frac{V}{8b}\right)^{\frac{V}{8b}}\cdot 8^N}{N^N\left(\frac{V}{8b}-N\right)^{\frac{V}{8b}-N}}\left(\frac{b}{V}\right)^N$$

$$=\frac{1}{N^N\left(1-N\cdot\frac{8b}{V}\right)^{\frac{V}{8b}-N}}\cong\frac{1}{N^N}. \qquad (29)$$

Now, to calculate the number of complexions in which there is overlapping amongst one pair of molecules only, $(N-1)$ representative points of $(N-1)$ molecules are distributed in such a way that 7 contiguous cells about each cell occupied by any one of $(N-1)$ representative points are vacant. The number of way, in which this is possible, is

$$\frac{V}{b}\left(\frac{V-8b}{b}\right)\left(\frac{V-2\cdot 8b}{b}\right)\cdots\left(\frac{V-\overline{N-2}\cdot 8b}{b}\right)=\frac{8^{N-1}\cdot\left(\frac{V}{8b}\right)!}{\left(\frac{V}{8b}-\overline{N-1}\right)!}.$$

Now, the remaining representative point is to be imagined to be coupled with one of the $(N-1)$ representative points, considered above, in such a way, that it occupies one of the 7 cells, contiguous to one of the cells occupied by one so that the total number of arrangement becomes

$$\frac{7 \cdot \left(\frac{V}{8b}\right)! \cdot 8^{N-1}}{\left(\frac{V}{8b}-N+1\right)!}.$$

Now, as the permutation of representative points amongst themselves will cause no difference, so the number of complexions will be

$$\frac{7 \cdot \left(\frac{V}{8b}\right)! \cdot 8^{N-1}}{N!\left(\frac{V}{8b}-N+1\right)!}.$$

So, the probability of occurrences of complexions having overlapping is

$$\frac{7 \cdot 8^{N-1} \cdot \left(\frac{V}{8b}\right)!}{N!\left(\frac{V}{8b}-N+1\right)!}\left(\frac{b}{V}\right)^{N-1} \cdot \left(\frac{b}{8b}\right) = \frac{7}{8^2} \cdot \frac{1}{N^N} \cdot \frac{1}{\left(1-\frac{N-1}{V} \cdot 8b\right)^{\frac{V}{8b}-N+1}}$$

$$\cong \frac{1}{N^N} \cdot \frac{7}{64}. \qquad \ldots \ldots \ldots \ldots \quad (30)$$

Similarly, the probability of occurrences of those complexions having overlapping amongst r pair only is

$$\frac{7^r 8^{N-r}\left(\frac{V}{8b}\right)!}{N!\left(\frac{V}{8b}-N+r\right)!} \cdot \left(\frac{b}{V}\right)^{N-r}\left(\frac{b}{8b}\right)^r \cong \left(\frac{7}{64}\right)^r \frac{1}{N^N}. \qquad \ldots \ldots \quad (31)$$

So, the average value of volume lost from covering spheres of each pair of molecules due to overlapping is

$$\overline{Z} = \frac{\sum_{r=0}^{\frac{N}{2}} \frac{1}{N^N}\left\{\left(\frac{7}{64}\right)^r \cdot 4r \cdot b^r\right\}}{\sum_{r=0}^{\frac{N}{2}} \frac{1}{N^N}\left(\frac{7}{64}\right)^r}$$

$$\cong \frac{\sum_{r=0}^{\infty} r\left(\frac{7}{64}\right)^r}{\sum_{r=0}^{\infty}\left(\frac{7}{64}\right)^r} 4b^r$$

$$\cong \frac{\frac{7}{64}\,\frac{1}{\left(1-\frac{7}{64}\right)^2}}{\frac{1}{1-\frac{7}{64}}} \cdot 4b''$$

$$= \frac{7}{64} \cdot \frac{64}{57} \cdot 4b'' = \frac{28}{57} b''. \quad .. \quad .. \quad .. \quad .. \quad (32)$$

So, the average value of volume lost from covering spheres due to overlapping per molecule is

$$\frac{14}{57} b''. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (33)$$

$$\therefore b = b_0 - \frac{14}{57} b'' = b_0\left(1 - \frac{14}{57} \cdot \frac{17}{32} \frac{Nb_0}{V}\right)$$

and so,

$$\gamma = \frac{14}{57} \cdot \frac{17}{32}. \quad .. \quad .. \quad .. \quad .. \quad (34)$$

Then,

$$p = \frac{NKT}{V}\left[1 + \tfrac{1}{2}\frac{Nb_0}{V} + \frac{5}{8}\left(1 + \frac{17}{57}\right)\frac{(\tfrac{1}{2}Nb_0)^2}{V^2}\right]$$

$$= \frac{NKT}{V}\left[1 + \frac{\beta}{V} + \frac{5}{8}\left(1 + \frac{17}{57}\right)\frac{\beta^2}{V^2}\right]. \quad .. \quad .. \quad .. \quad (35)$$

In presence of Van der Waal's field of force this becomes

$$p + \frac{\alpha}{V^2} = \frac{NKT}{V}\left[1 + \frac{\beta}{V} + \frac{5}{8}\left(1 + \frac{17}{57}\right)\frac{\beta^2}{V^2}\right]. \quad .. \quad .. \quad .. \quad (36)$$

The second virial coefficient (i.e. coefficient of $\frac{\beta^2}{V^2}$) as obtained here, differs from the usually accepted value by 30% only.

Conclusion.

The value of virial coefficient obtained by Boltzmann and others, which is believed to be correct is $\frac{5}{8}$. The calculation in section 8, which takes account of frequency of occurrence is expected to yield a value, somewhat more accurate than that obtained by Boltzmann. However, the present line of thought at least indicates that calculations improving the hitherto accepted result, $\frac{5}{8}$, are possible. Anyway, detailed informtiaon from properly designed experiments, together with a thorough and minute revision of the usual arguments probably in the light of the discussion made in the paper, is expected to throw more light on this subject.

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Summary.

The present paper is divided mainly into two parts. In the first part, the Planck-Saha-Bose Equation of State, which will be taken as basis for deducing more accurate equations of state in later development, has been obtained by the statistical method, developed by the author in some of his previous papers. In the second part, on taking the overlapping of the Deckungsphären into consideration by the above method after suitable modifications, the usually accepted value of the second virial coefficient of the equation of state has been obtained. After this, the relation (or better equivalance) between this method and that of Boltzmann has been discussed, and some of the unsatisfactory features, common in both the methods, have been pointed out. Finally a modified method, which is free from the above mentioned unsatisfactory features up to some extent, has been suggested, and a value of the second virial coefficient obtained by rough calculations from this method is, of course, found to deviate from the accepted value by about 30%. But from the theoretical discussions, put forward in the paper, the value obtained here, appears to be more reliable, and is expected to be verified when more accurately designed experiments will be performed.

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ELECTRIC CHARGES OF RAIN-DROPS.

*By S. K. Banerji, *D.Sc.*, *F.N.I.*, *F.R.M.S.*, *Professor of Mathematics, College of Engineering and Technology, Bengal, Jadavpur, and* S. R. Lele, *M.Sc.*, *Bombay.*

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Introduction.

In spite of the many investigations that have been made on the origin of electricity of rain there are many points which remain as obscure as ever. Simpson's 'Breaking Drop' theory was at one time considered to describe a major process which was in operation in the production of electricity of cloud. In Simpson's experiments drops of distilled water were allowed to fall through a nozzle and these were broken in a vertical blast of air. In 1938, the senior author showed that the results of these experiments were not directly applicable to breaking of drops in the atmosphere. In the laboratory experiments, the reaction between the liquid and the nozzle makes the drops leave the nozzle with an initial positive charge and give the nozzle a negative charge, with the result that while the drops after being broken by the air current get a charge of 0·023 e.s.u./c.c., the total charge in the air is less than half this amount. In the atmosphere there is no nozzle; the drops may form on ions or nuclei, and may have an initial positive or negative charge, but if they are broken in a current of air, the total charge in the air which will be derived from 1 c.c. will be about minus 0·0092 e.s.u. and the charge acquired by the drops by this operation will also be equal to this amount but positive in sign. Rain-drops always contain a certain amount of impurities; when evaporated to dryness, 100,000 parts of rain-water will give about 0·34 parts of solid matter and most of this consists of sodium chloride and organic matter. This is equivalent to a concentration of $3{\cdot}4\times10^{-4}$ per cent. Experiments show that when drops are broken in a vertical blast of air or by striking against each other, they become negatively charged when the concentration exceeds 5×10^{-5} per cent. The concentration of impurities in rain-drops is so near the transition point that we can develop very little positive charge by the breaking of drops.

The alternative theory of 'carriers' proposed by Wilson (1929) has recently been subjected to experimental tests by Gott (1933). In as much as the process outlined therein involves the capture of ions of either sign by a falling drop in a pre-existing electric field, the growth of charge in the drop, starting from the neutral state, is explained, but the field sets a limit to the charge which the drop can acquire in this way. It is shown that in the presence of ions of both signs carrying equal currents, the drop collects no net charge in fields greater than a certain critical field. In fields

less than the critical field it collects more ascending than descending ions and so gains a net charge, which does not increase indefinitely but tends to a limiting value. The limiting charges observed are, for a field of 143 volts/cm., $0{\cdot}58\times10^{-2}$ e.s.u. and for a field of 196 volts/cm., $0{\cdot}81\times10^{-2}$ e.s.u., while in a field greater than 536 volts/cm., the charge acquired is negligible. The largest charge observed in the course of the experiments described by Gott was equal to about 10^{-2} e.s.u. per drop and since the volume of a drop was $4{\cdot}2\times10^{-2}$ c.c., this is equal to 0·2 e.s.u. per cubic centimetre. This maximum charge is slightly smaller than the actual average charge observed on rain-drops.

There can be little doubt that the processes suggested by Wilson and Simpson are both in operation in clouds, in which a strong vertical motion exists. Probably also the collisions of drops, as outlined in Elster and Geitel's theory, come into operation in some way in producing a separation of charge. Furthermore, in the upper parts of a thunder-cloud above the freezing level, the striking of ice particles against each other must make them negatively charged, the positive charge being given to the air. It is, therefore, necessary to find out the relative importance of these various processes by studying the nature of the charges collected by individual drops in thunder-storm or non-thunder-storm rain and also whether these processes by themselves are sufficient to explain the full charges on such drops and if not whether other, and more fundamental, processes come into operation.

The main difficulties in understanding the mechanism of generation of electricity have been that no detailed analysis has hitherto been made of the charge on individual drops of rain. The observations described in this paper[1] were made in the years 1931 and 1932 in the Colaba Observatory at Bombay, and in 1935 and 1936 at Poona. In addition to the Simpson's apparatus for recording the charge of rain collected every two minutes, an apparatus was set up in 1930 in the Colaba Observatory, Bombay, for recording the charge on individual drops of rain. These observations indicate that both positively and negatively charged drops are present in the rain falling from the different parts of a thunder-cloud or an ordinary cloud. When the rain collected in any particular interval of two minutes is positively charged, the result merely means that there is an excess of positively charged drops. Similarly when the rain as a whole in any small interval is negatively charged, there is an excess of negatively charged drops. The average positive charge per drop is about 0·021 e.s.u. and the average negative charge per drop is about 0·023 e.s.u. in non-thunder-storm rain. In thunder-storm rain, the average positive charge per drop is 0·051 e.s.u. and the average negative charge is 0·057 e.s.u. The average radius of rain-drops whose charges were measured is about 0·12 cm. In the classical experiments of Millikan, the oil drops were of radius 2×10^{-4} cm., and on the average there were about 10 ions in a drop. In freshly formed clouds and in fogs, the particles have diameters of the order 10^{-3} cm. Assuming that in a cloud-particle of this size there are 50 ions on the average and assuming that a rain-drop of radius 0·1 cm. has been formed by coagulation of the cloud particles, the total charge on the rain-drop will be about 0·023 e.s.u., that is to say, of the order actually observed. The number of ions in a Millikan drop has been found to vary from 1 to 130, and on the assumption of a similar variation, the charge on a rain-drop supposed to have been formed by coagulation of cloud particles should be expected to vary within wide limits. Since the charge of an ion is $4{\cdot}7\times10^{-10}$ e.s.u., there must be in an average positively or negatively charged drop about 10^8 positively or negatively charged ions. Any satisfactory theory of generation of electricity in rain must explain how this enormous number of positive or negative ions attach themselves to rain-drops. Before we proceed to examine this and other points it is necessary first to analyse and collect together the observed results.

[1] The publication of this paper has been unavoidably delayed, and in the meantime a paper by Hutchinson and Chalmers has appeared in *Quart. Journ. Roy. Met. Soc.*, Vol. 77, 1951

A preliminary account of these experiments was published in *Nature*, Vol. 130, p. 998-999, Dec. 1932.

Although all the experiments were completed in 1935-36, the publication of this paper has been long delayed. This was partly due to the fact that the observations taken at Poona showed that the charges on individual drops recorded at Bombay were about ten times larger than expected, and this was subsequently traced to an unfortunate mistake in the computation of the capacity of the recording system in electrostatic units, which gave its value ten times more than its real value. Owing to this mistake, the figures for charge per drop in e.s.u. would be one-tenth of those given in the above-mentioned article in *Nature*. The delay in publication is also partly due to my preoccupation during the War years.

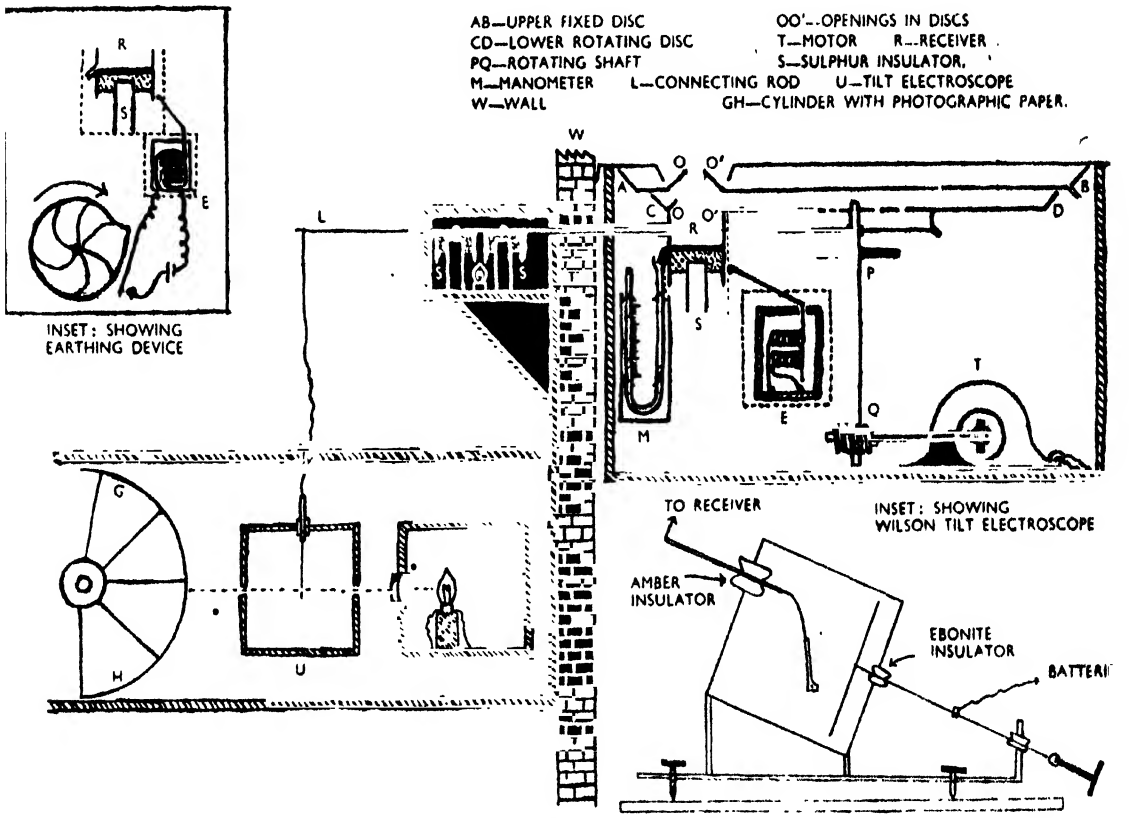


FIG. 1.

EXPERIMENTAL ARRANGEMENT FOR RECORDING CHARGE ON INDIVIDUAL DROPS OF RAIN.

In designing a suitable experimental arrangement for recording the charge on individual drops of rain, it is necessary to take every precaution with a view to avoid all spurious effects. The arrangement must be such that a drop enters the receiver without splashing on the side, and that a second drop has no access into the receiver until the charge of the first has been recorded and the apparatus earthed. The electrometer for recording the charge must not only be highly sensitive but also dead-beat so that it can record the charge of drops in quick succession without introducing free vibrations of the system into the record. In practice, it is not easy to satisfy all these conditions rigidly.

The apparatus used, although somewhat imperfect, is shown diagrammatically in figure 1 and is divided into three parts, namely (1) the receiving system, (2) the insulated connecting system, and (3) the recording system. The receiving system consists of an upper fixed disc of diameter 32 cm. with an opening in the form of a cylindrical funnel near the periphery. This opening, which can be adjusted to different sizes to suit different intensities of rain, is provided with trap arrangement, as shown in the diagram, so that a drop striking the sides is caught and led away. It has on the average a diameter of 1·4 cm. Below this disc, there is a disc of diameter 27 cm., rotating uniformly round its central axis once in about 25 seconds. The rotation was maintained by a small alternating current electric motor, the speed being reduced by double worm gears. Near the periphery of the rotating disc, there is a cylindrical opening with trap arrangement and of diameter 2·4 cm. Once during each rotation, this opening comes directly below the opening in the upper fixed disc. The diameter of the opening in the upper disc has been determined by trial so that with moderate intensity of rain only a single drop will pass through both openings. A cylindrical vessel of diameter 7·8 cm. and of height 5·6 cm. resting on double jacket sulphur insulators as shown in the diagram is placed directly below the two openings and receives the drop. A manometer is attached to the receiving vessel and gives a measure of the size and number of drops. The manometer is usually read by eye but a recording arrangement is easily made by making a beam of light focus the meniscus of the coloured oil column (a solution of Iodine in Turpentine) in the outer limb of the manometer on the same sheet of photographic paper which records the charge of the drops. It is not easy to arrange the experimental condition so that each drop after entering the receiver flows into the manometer. If the level is suitably adjusted and a small quantity of water is allowed to remain in the receiver, then after one, two or three drops, depending upon their size, enter the receiver, a corresponding quantity of water flows into the manometer. Careful eye observation is necessary to find out how many drops have entered the receiver before water has flown into the manometer. If the drops are of very small size, the arrangement is not very sensitive and no displacement of the manometer occurs until 3 or 4 drops have entered the receiver. The shaft which rotates the disc also works a contact arrangement. As soon as the charge of the drop has been recorded, an arm attached to the axle makes an electric contact and excites an electro-magnet. The electro-magnet thus attracts an earth connected lever which by making a momentary contact earths the receiver. The electro-magnet and the contact arrangements and all other parts except the end of the earthing lever were covered by earth-connected metal-sheets.

The receiving apparatus was placed on a bracket fixed to the outer wall of a photographic room and covered all round by earth-connected metal sheets leaving on the top sufficient opening for the rain-drop to enter the receiver. The wire connecting the receiver with the recorder was made to pass through a hole in the wall. An earth-connected metal tube was placed concentrically around the wire in order to protect it from stray electric fields. The insulators used in leading the wire from the receiver to the recorder were of sulphur and of the design shown in the diagram.

Before the records were started all insulations were scraped and heated by heating lamps. But when the instrument was in operation all heating lamps were disconnected in order to avoid the effect of artificial fields. The recording apparatus consisted of a Wilson tilt electroscope. The gold-leaf was of length 3·8 cm. and of breadth 1 mm. except at the lower end which was a rectangular piece of breadth 3 mm. and length 2 mm. This rectangular piece was twisted at right angles and a fine pin-hole made at its centre. Light from a point source (a Pathé-Baby Projector lamp) was passed through a small slit and focussed by means of a short focus lens placed just outside the window of the electroscope, and was then allowed to fall as a transverse beam of length of about 1 mm. over the

pin-hole. The transmitted light through the pin-hole formed a sharp point on a photographic paper placed 12 cm. away from the gold-leaf. A large magnification of the movement of the gold-leaf was obtained in this way. The photographic paper was wrapped round a cylinder which was rotated round a spiral by clock-work so as to give a speed of 1·2 cm. per minute on the photographic paper. The driving clock was a pendulum one and gave uniform speed, the time marks were obtained by cutting off the light at known instants. As each rain-drop entered into the receiver, a displacement of the speck was obtained either to the right or to the left of the zero (earthed) position according to the sign of charge and as the system was earthed immediately afterwards, the speck came back to zero. The intensity as well as the sign of the charge of drops was, therefore, given by the successive displacements either to the right or to the left.

The capacity of the receiver and the recording system was 60 cm. Two volts applied to the receiver produced a deflection of 0·9 cm. Therefore, 1 cm. of deflection was equivalent to

$$\frac{2\times 60\times 10}{300\times 9} \text{ or } 0{\cdot}44 \text{ e.s.u.}$$

Test experiments.

The following test experiments were made. A number of drops were allowed to fall on the receiving apparatus from an insulated metal funnel in which a coil of wire was inserted, and which was charged to a known potential with respect to earth. The diameters of the drops were determined by collecting a certain number of them and measuring the volume. Knowing the potential and the volume of each drop the charge per drop is easily obtained. The deflection produced on the photographic paper as the cumulative effect of a definite number of charged drops falling on the receiver is measured under a microscope and from this the charge corresponding to 1 cm. of deflection on the photographic paper is readily calculated. For instance, in one experiment the following results were obtained:—

Volume of 200 drops	24	c.c.
∴ radius of each drop	0·3	cm.
Voltage to which the drops were charged	80	volts.
∴ the charge on each drop	0·008	e.s.u.
48 drops produced deflection of	0·88	cm.
The charge corresponding to a deflection of 1 cm. is	0·44	e.s.u.

The results of the calibration experiments are summarized in Table I.

Simultaneously with the apparatus described above for recording the charge on individual drops of rain an apparatus for recording the charge collected every two minutes was maintained in continuous action. This was of the usual Simpson type.

An electrograph recording potential gradient, with an 'ionium' collector was also maintained in continuous action.

3. General discussion of the charge of rain-drops.

The kind of records obtained on account of communication of charge into the apparatus by successive drops and the earthing of the system, as soon as the charge of each drop is recorded, is shown in Plate II. In this Plate typical records showing the charge of thunder-storm rain-drops and of non-thunder-storm rain-drops have been reproduced. It will be seen that each drop produces an appreciable deflection and that in thunder-storm rain the

TABLE I.

Plate voltage of tilt electroscope	..	..	190 volts.
Radius of an average drop ..	..	..	0·3 cm.
Charge per drop ..	..	..	0·008 e.s.u.

Drops charged to +80 volts.			Drops charged to −80 volts.		
No. of observations.	No. of drops entering the receiver.	Deflection in cm.	No. of observations.	No. of drops entering the receiver.	Deflection in cm.
1	40	0·76	1	40	0·79
2	40	0·73	2	40	0·71
3	40	0·71	3	40	0·74
4	40	0·73	4	40	0·71
5	48	0·88	5	48	0·85
6	48	0·88	6	48	0·88
7	48	0·88	7	48	0·85
8	48	0·88	8	48	0·94
9	48	0·91	9	48	0·91
10	48	0·88	10	48	0·88
11	48	0·85	11	48	0·88
12	48	0·88	12	48	0·88
13	76	1·38	13	76	1·44
14	76	1·44	14	76	1·41
15	76	1·38	15	76	1·41
16	76	1·47	16	76	1·38
17	88	1·62	17	88	1·62
18	88	1·62	18	88	1·59
19	88	1·62	19	88	1·68
20	88	1·62	20	88	1·62
21	97	1·79	21	97	1·79
22	97	1·79	22	97	1·79
Mean deflection per drop = 0·018 cm.			Mean deflection per drop = 0·018 cm.		
1 cm. of deflection = 0·44 e.s.u.			1 cm. of deflection = 0·44 e.s.u.		

drops are slightly more intensely charged than in non-thunder-storm rain. It will be observed that if the rain-drops are of diameter 0·2 cm., and if the centre of any drop falls anywhere within 0·1 cm. of the periphery of the adjustable upper opening of 1·4 cm. in diameter, then it will strike the side and get discharged. If, however, its centre falls anywhere within the circle of radius 0·6 cm., then it will pass through. The chance of a drop of this size striking the side is, therefore, $2\pi \times 0{\cdot}7 \times 0{\cdot}1 : \pi \times 0{\cdot}6 \times 0{\cdot}6$ or 14 : 36.

It would be wrong to conclude from this that on the average every third drop will reach the receiver with no charge on it, because the rotating disc below the upper opening completely modifies the condition. The rotating disc closes the upper opening in less than half a second. A drop which will strike the periphery of the upper opening will almost in every case be caught by this rotating disc. It is clear that only those drops which fall through near the centre of the upper opening will have a chance of passing through the opening in the rotating disc. It is, therefore, found in practice that a comparatively small number of drops reach the receiver without any charge. The general characteristic of the charge of thunder-storm and non-thunder-storm rain-drops can be clearly seen from Table II which has been based on the measurement of charges on 2,500 drops. In making the tabulations all drops were neglected whose charge was less than 0·006 e.s.u.

TABLE II.

	Charge per drop (e.s.u.)					
	Positively charged drops.			Negatively charged drops.		
	Mean.	Mean Max.*	Absolute Max.	Mean.	Mean Max.*	Absolute Max.
Thunder-storm rain ..	0·055	0·194	0·244	0·061	0·226	0·374
Non-thunder-storm rain	0·041	0·118	0·195	0·045	0·122	0·241

* Average of maximum reached on different dates.

It is to be noted that a drop of radius 0·1 cm. and having 0·05 e.s.u. has a potential of 150 volts while if it has a charge of 0·25 e.s.u. its potential is 750 volts. It was noticed that when all drops whose charge is less than 0·006 e.s.u. are neglected in making the tabulations, the number of drops neglected is considerably more in non-thunder-storm rain than in thunder-storm rain. The results given above in respect of thunder-storm and non-thunder-storm rain-drops are, therefore, not strictly comparable with each other. Another table was consequently prepared in which all drops whose charge was less than 0·001 e.s.u. was neglected; this was the limit up to which tabulation was possible under the microscope, with the sensitiveness adopted in the recording system.

The results are shown in Table III.

TABLE III.

	Charge per drop (e.s.u.).					
	Pos itively charged drops.			Negatively charged drops.		
	Mean.	Mean Max.*	Absolute Max.	Mean.	Mean Max.*	Absolute Max.
Thunder-storm rain ..	0·051	0·194	0·244	0·057	0·211	0·374
Non-thunder-storm rain	0·021	0·118	0·195	0·023	0·122	0·241

* Average of maximum reached on different dates.

Note:

Thunder-storm rain.

Number of positive drops tabulated ..	..	.. 600
Number of negative drops tabulated ..	..	.. 790
Number of drops neglected ..	..	.. 23 (percentage 1·6)

Non-thunder-storm rain.

Number of positive drops tabulated	.. 1,070
Number of negative drops tabulated	.. 1,288
Number of drops neglected	.. 297
	(percentage 12)

It will be seen that even with the limit of 0·001 e.s.u. the percentage of drops neglected in the case of non-thunder-storm rain was 12, while in the case of thunder-storm rain, it was only 1·6. It is probable that a certain number of these neglected drops reached the receiver discharged as a consequence of their striking the periphery.

An analysis of the records shows that both positively and negatively charged drops are present in the rain received from any part of the cloud. When the Simpson apparatus shows that the rain received during any interval is positively or negatively charged as a whole, it is found that there is an excess of positively or negatively charged drops. When we analyse the figures given in Table II or Table III we find that both in thunder-storm and non-thunder-storm rain, the negative drops are slightly more intensely charged than the positive drops. The mean charge per drop in thunder-storm rain is considerably greater than the mean charge per drop in non-thunder-storm rain. The mean charge per drop in the case of non-thunder-storm rain would probably become slightly less than the figure given if all the drops could be included in the tabulation. The absolute maximum value of charge per drop obtained during the period of observation in the case of thunder-storm rain considerably exceeds that in the case of non-thunder-storm rain. In order to bring out more conspicuously the differences in the charges of drops in the case of thunder-storm and non-thunder-storm rain Table IV has been prepared.

At Poona, a Lindeman electrometer was used. The potentials applied to the plates were +30 volts and −30 volts. With these imposed potentials, the deflection per volt as observed through the microscope was 5·5 divisions. The receiving system although of the same pattern was redesigned, using the minimum amount of metal, so as to have as small a capacity as possible. The capacity was 8 cm., so that a deflection of 1 division was equivalent to $4{\cdot}8\times10^{-3}$ e.s.u. (or approximately 5×10^{-3} e.s.u.). Of the 320 drops whose charges were measured, 151 were positively charged and 169 negatively charged. The following table gives an analysis of the charges obtained in these measurements :—

	Charge per drop (e.s.u.)					
	Positively charged drops.			Negatively charged drops.		
	Mean.	Mean Max.	Absolute Max.	Mean.	Mean Max.	Absolute Max.
Thunder-storm rain ..	0·046	0·120	0·125	0·062	0·165	0·192
Non-thunder-storm rain	0·020	0·065	0·120	0·048	0·080	0·105

At Poona, the charges brought down by rain, as observed in these experiments were preponderatingly negative.

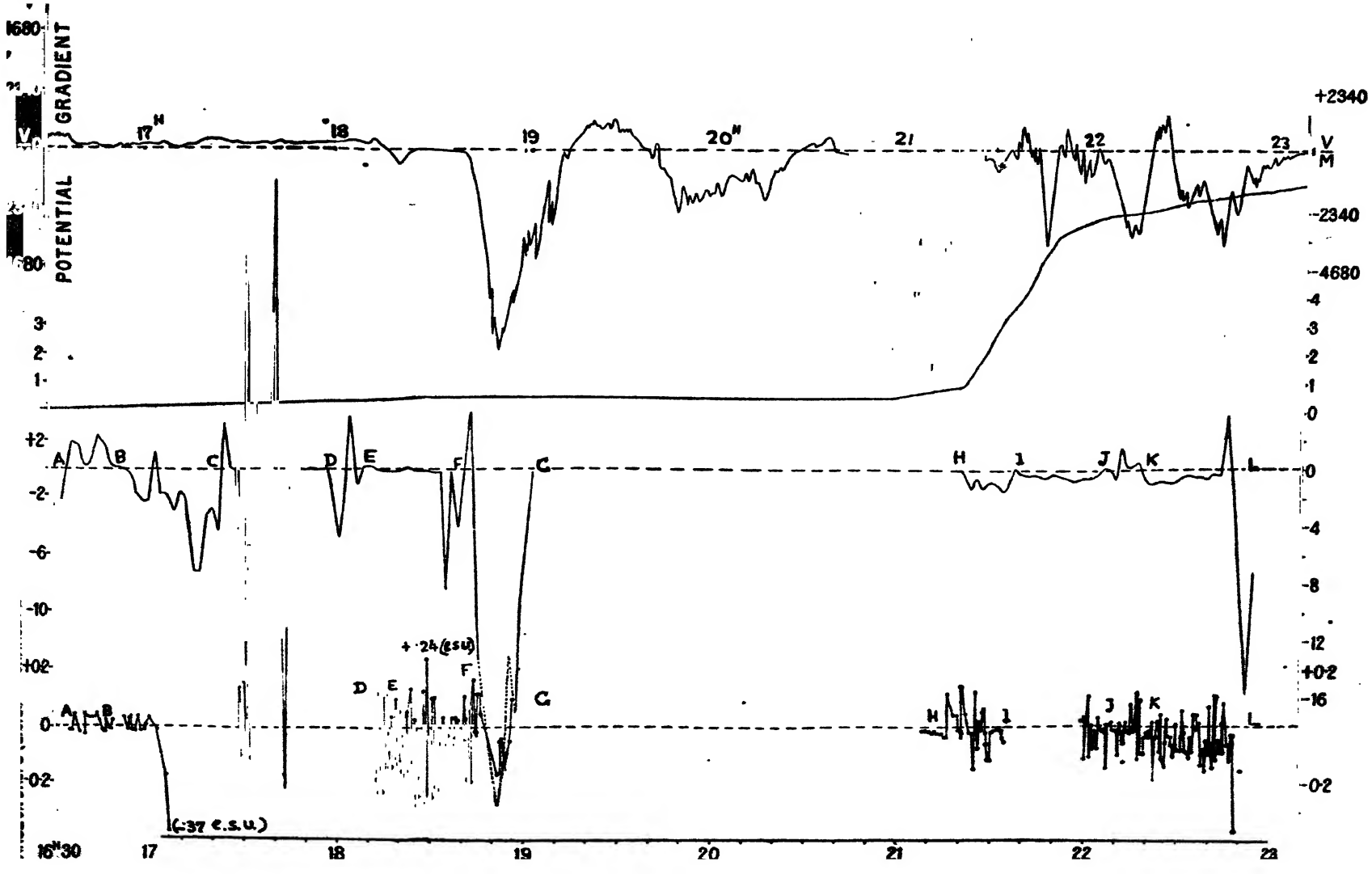
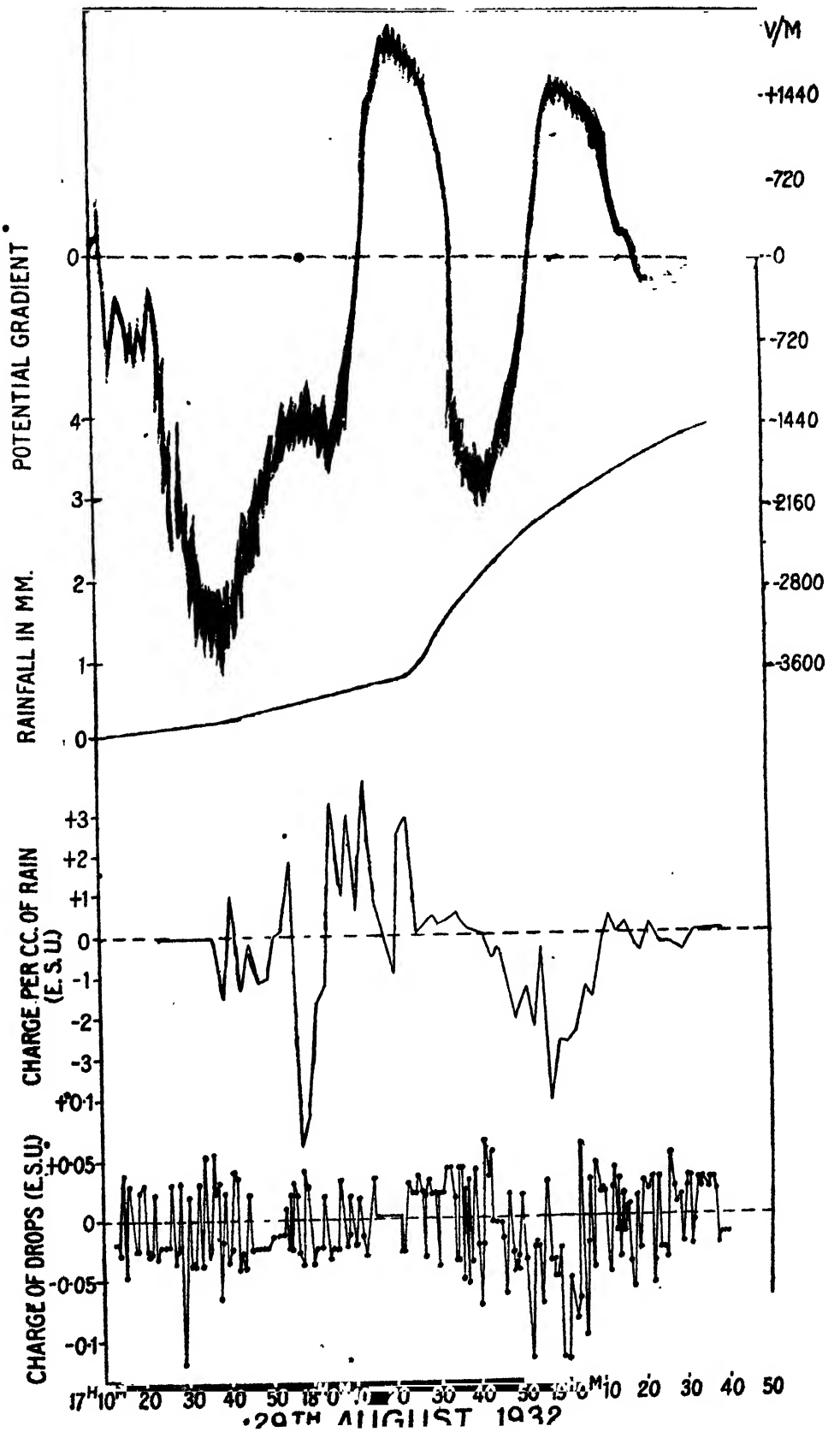

POTENTIAL GRADIENT
1680
80
3
2
1
17H
18
19
20H
21
22
23
+2340
V/M
-2340
-4680
4
3
2
1
0
+2
-2
-6
-10
-12
+0·2
-16
-0·2
A
B
C
D
E
F
G
H
I
J
K
L
+·24(e.s.u)
(-37 e.s.u)
16H30
17
18
19
20
21
22
23

TABLE IV.

	Total No. of drops analysed.	Percentage of drops with charge.											
		Of 0·2 e.s.u. or more.		Between 0·1 e.s.u. and 0·2 e.s.u.		Between 0·05 e.s.u. and 0·1 e.s.u.		Between 0·01 e.s.u. and 0·05 e.s.u.		Between 0·005 e.s.u. and 0·01 e.s.u.		Between 0·001 e.s.u. and 0·005 e.s.u.	
		Pos.	Neg.	Pos.	Neg.	Pos.	Neg.	Pos.	Neg.	Pos.	Neg.	Pos.	Neg.
Thunder-storm rain	600 Pos. 790 Neg. without charge 23	0·28	1·4	4·0	7·6	12·3	14·4	20·9	28·0	3·2	2·5	1·9	2·1
Total ..	1,413											below 0·001 e.s.u.	1·6%
Non-thunder-storm rain.	1,070 Pos. 1,288 Neg. without charge 297		0·5	2·0	2·4	4·2	5·3	13·4	16·0	6·8	7·1	14·4	17·0
Total ..	2,655											below 0·001 e.s.u.	11·1%


V/M
+1440
-720
0
-720
-1440
-2160
-2800
-3600
POTENTIAL GRADIENT
RAINFALL IN MM.
CHARGE PER CC. OF RAIN (E.S.U.)
CHARGE OF DROPS (E.S.U.)
+3
+2
+1
0
-1
-2
-3
+0·1
+0·05
0
-0·05
-0·1
4
3
2
1
0
17H 10M 20 30 40 50 18 0 10 20 30 40 50 19 0 10 20 30 40 50
29TH AUGUST 1932

that the heavy rainfall (represented by the portion *AC*, on the rainfall curve) was on the whole positively charged. During the interval 82 positively charged drops and 48 negatively charged drops were recorded. The intense negative field which was attained during the interval *BC*, was clearly due to the removal of large quantities of positive charge by rain. This was followed by a decrease in the intensity of rain and the drops brought down an excess of negative charge. During the interval *CD*, 16 positively charged drops and 30 negatively charged drops were photographed. The removal of the excess negative charge, accompanied probably with a regeneration of positive charge, made the field to become gradually positive.

5. Discussion of the charge on non-thunder-storm rain-drops.

The electrical records of non-thunder-storm rain may be divided into three distinct classes, namely,

(*a*) Those associated with intense negative gradient,
(*b*) Those associated with comparatively feeble negative gradient,
(*c*) Those associated with an increase in the positive gradient, large or small.

Examples of all these types are met with during the South-West monsoon. Production of negative gradient is, however, more common during a shower than the production of an increase in the positive gradient. We will now proceed to discuss the essential features of the various types.

(*a*) *Non-thunder-storm rain associated with intense negative gradient.*

A typical example of this is furnished by the record obtained during the passage of a nimbus cloud on the 23rd June, 1932 (fig. 5). The sky was overcast and rainfall of about 5 mm. was recorded. As soon as the shower commenced the field decreased in intensity, became negative and reached a negative value of about 850 V./M. The records show that during this period the rain was on the whole positively charged; of the drops whose charges were recorded during the period, 20 were positively charged and 14 negatively charged. Increase in the negative gradient was clearly due to the removal of positive charge in excess of negative, thus making the cloud to have a growing increase of negative charge. Ultimately the excess of negative charge was so great, that the process was reversed and more drops with negative than positive charge fell and consequently the rain was on the whole negatively charged. The removal of the excess negative charge gradually led to a reversion of the field towards positive. It is remarkable how the fluctuation of the field responds to removal by rain of excess positive or excess negative charge. During the period marked *PQ* in the potential gradient record, a fairly large number of drops with positive charge fell, and the intensity of the field tended twice to increase towards negative. Similar remarks apply to the portion *LM* of the potential gradient record.

Another example of comparatively large negative gradient attained during shower is furnished by the records obtained on the 2nd September, 1932, (fig. 6). The fluctuation of the gradient is more complex in this record than in the previous one. This nimbus cloud appears to be a remarkable one, because the 2-minutes charge record shows that throughout the passage of the cloud, the rain was positively charged. This is confirmed by the drop records. During the period 66 drops were recorded with positive charge and 26 with negative charge. The fluctuation in the field in this, as in the previous case is easily seen to be dependent, to a large extent, on the rate at which positive or negative charge was being removed by the rain, the increase towards positive associated with the peak *P* in the potential gradient record followed the removal of a certain quantity of negative charge and so also in the case of the peak *Q*. The maximum negative gradient

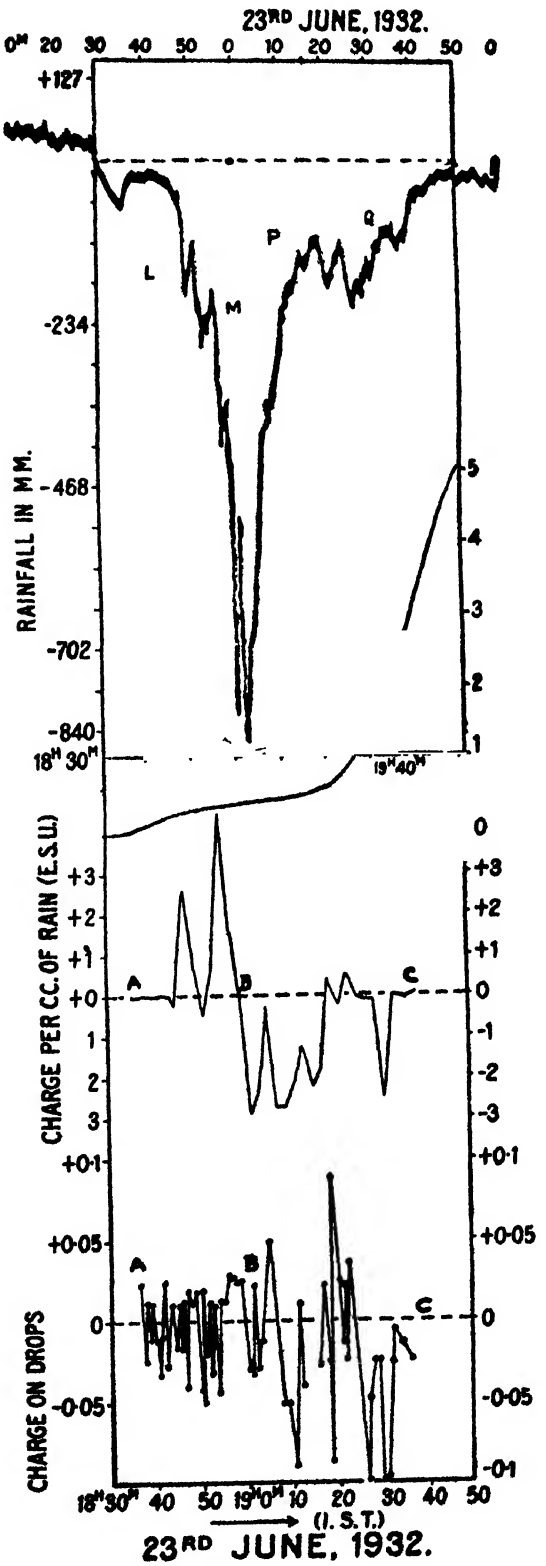

23RD JUNE, 1932.
0H 20 30 40 50 0 10 20 30 40 50 0
+127
-234
-468
-702
-840
RAINFALL IN MM.
L
M
P
Q
5
4
3
2
1
18H 30M
19H40M
CHARGE PER CC. OF RAIN (E.S.U.)
+3
+2
+1
+0
1
2
3
+0·1
+0·05
0
-0·05
A
B
C
-1
-2
-3
-0·1
18H30M 40 50 19H0M 10 20 30 40 50
(I. S. T.)
23RD JUNE, 1932.

Fig. 5.

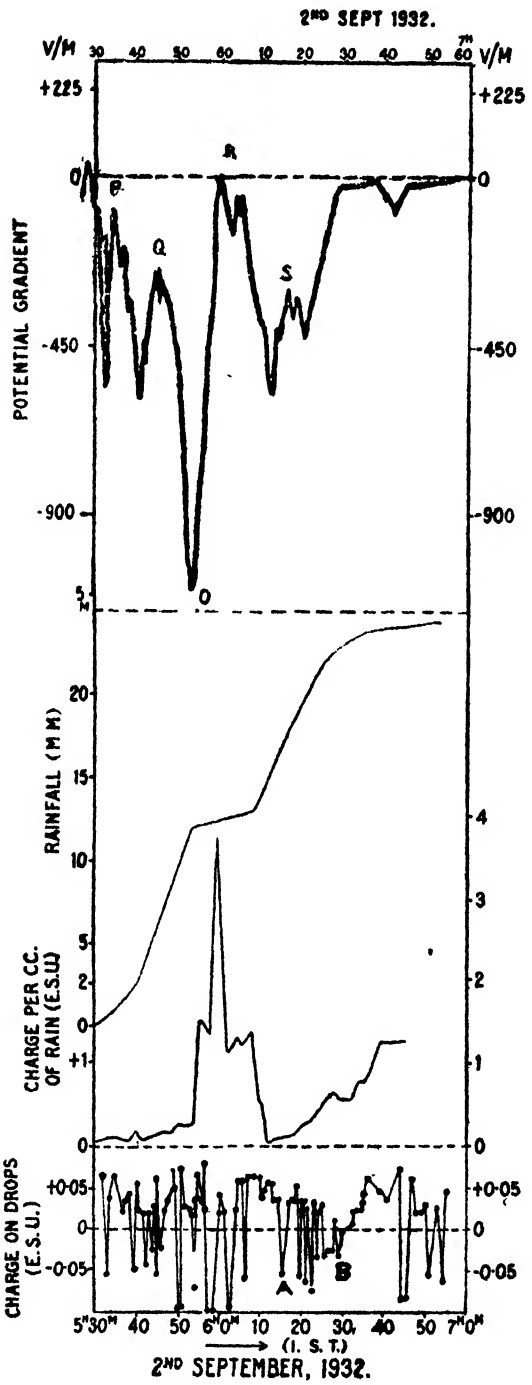


FIG. 6.

indicated by the peak *O*, was reached, when the intensity of rain decreased, and consequently positive charge was not being removed as rapidly as before. The decrease in rain was apparently associated with a regeneration of positive charge in the cloud, and consequently the gradient tended to revert to positive, but soon afterwards the intensity of rain increased, a very rapid removal of positive charge

commenced and consequently the field became negative again. The reversion towards positive, indicated by the peak S, is associated with an increase in the rate of removal of negative charge. We see indeed from the portion marked AB in the drop record, that during the period the negative charge was being removed at greater rate than before.

(b) Non-thunder-storm rain associated with feeble negative gradient.

The records obtained on the 10th July, 1932, (fig. 7) illustrate the case of weak positive gradient followed by a weak negative gradient attained during a shower.

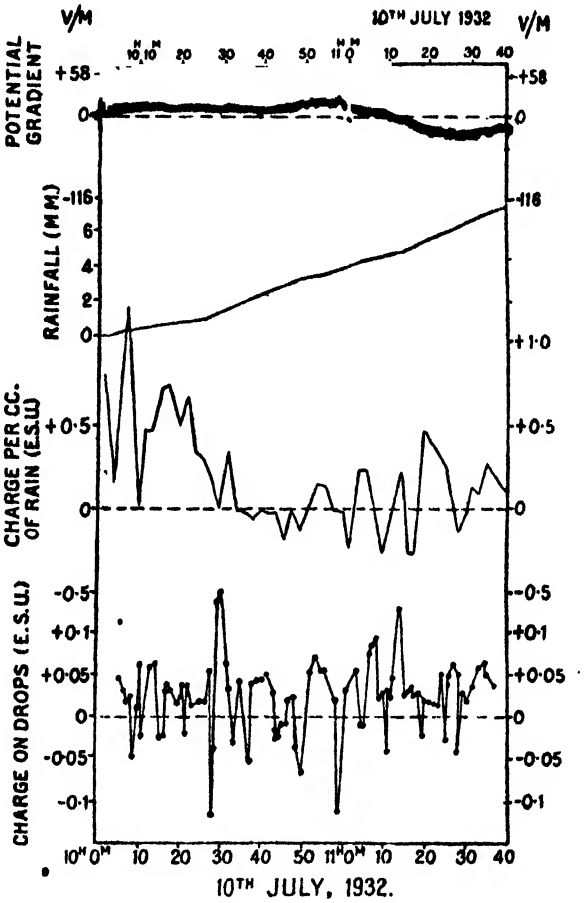


FIG. 7.

The intensity of the gradient near the ground surface seems to be dependent largely on the state of separation of positive and negative charges in the cloud. The intensity of separation of charges would appear to depend on the vertical air motion in the cloud, the greater the vertical motion, the greater is the separation. On the 23rd June, 1932, (fig. 5), the cloud was distinctly of cumulo-nimbus type and suggested considerable vertical motion and so also that on the 2nd Sept., 1932, (fig. 6). On the 10th July, 1932, (fig. 7), on the other hand, the sky was overcast with moving nimbus cloud, in which the horizontal motion was more conspicuous than the vertical motion. The low potential gradient under the cloud would thus appear to be due to very little separation of positive and negative charges in it.

The reduction of the positive gradient and its becoming negative towards the end is due to more positive charge being removed from the cloud than negative.

An illustration of a slightly different type of feeble negative gradient is furnished by the records obtained on the 15th July, 1932, (fig. 8). On this day also

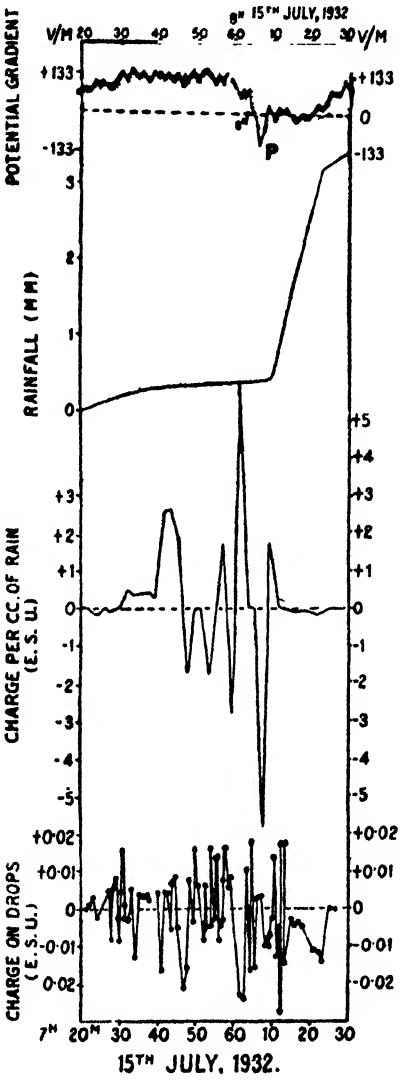


FIG. 8.

the sky was completely overcast with nimbus clouds and there was a strong horizontal wind. The drops reached the receiver in a very slanting direction. The positive and negative drops were more or less mixed up in the cloud and did not apparently become concentrated in the different parts of the cloud. Drops of both signs fell from the cloud. The reduction of the potential gradient to negative (marked *P* in the record) was due to a more rapid removal of the positive charge than negative at the time. The subsequent increase in the intensity of rain was associated with the removal of more negative drops than positive; the field, therefore, reverted to positive.

(c) Non-thunder-storm rain associated with an increase in the positive gradient.

An example of the increase in the positive potential gradient is furnished by the records obtained on the 22nd July, 1932, (fig. 9). The increase occurred during

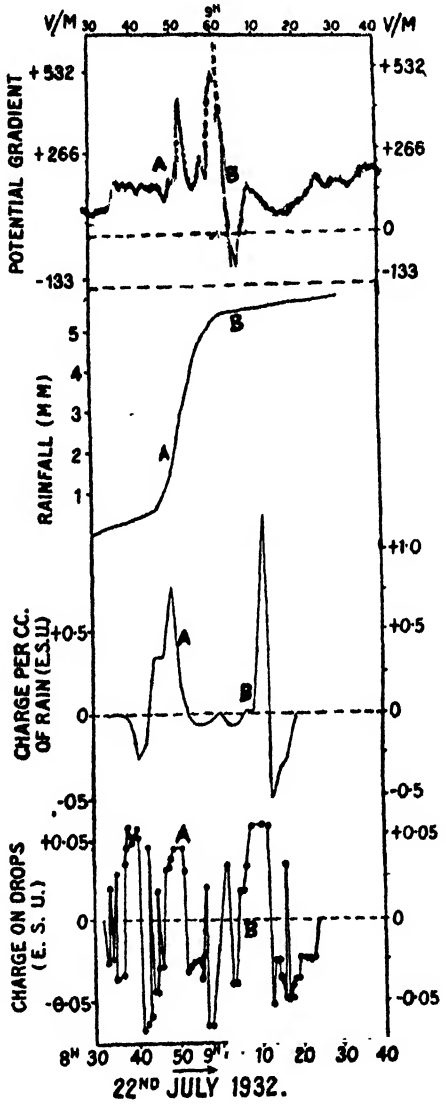


FIG. 9.

the period (marked AB on the records) when the intensity of rain was maximum. The charge record shows that this increase was due to a greater removal of negative charge from the cloud than positive. This was followed by a greater removal of positive charge; consequently the field became negative for a short while. The field reverted again to positive soon after, as rain began to remove more negative charge than positive.

The records obtained on the 30th and 31st July, 1932 (fig. 10), illustrate a case in which, except on one occasion (marked A on the record), the gradient never reached a negative value, and in general it showed a slightly higher value than the normal positive. This generally higher value appears to be due to the number of

negative drops removed by rain being on the whole greater than the number of positive drops.

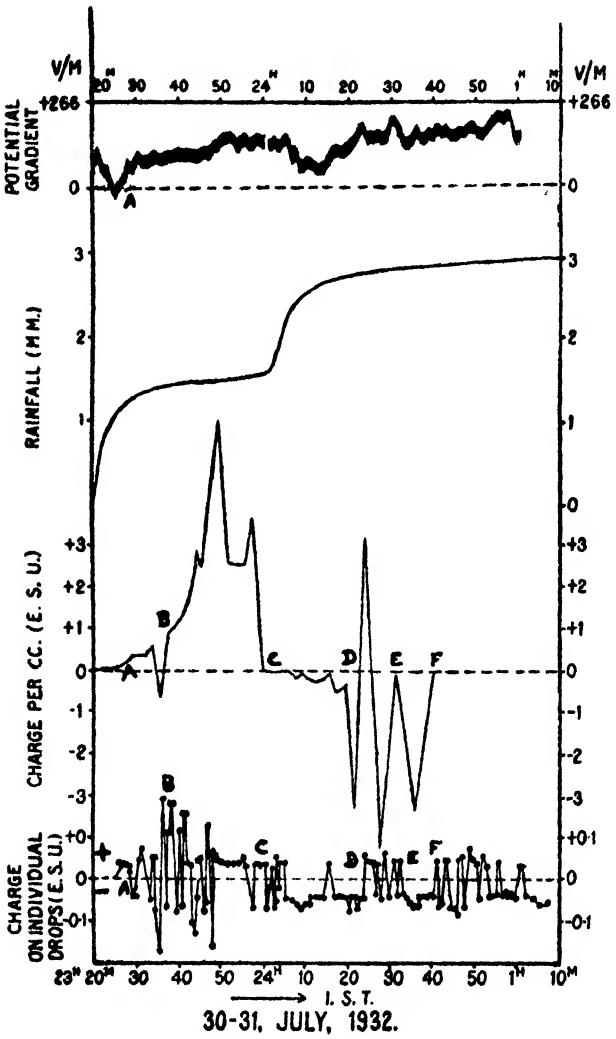


FIG. 10.

The drop record shows 72 negative drops against 62 positive drops. The comparatively low gradient throughout is obviously due to the charges not having separated much from each other; and the fluctuation in the field at any stage can be attributed to a greater or less removal of positive or negative drops. The negative peak, for instance, is seen to have been preceded by an excess removal of positive drops and followed by an excess removal of negative drops.

6. ANALYSIS OF CHARGE OF RAIN-DROPS.

We now proceed to make an analysis of the charge of rain-drops. The most important point to consider is whether the average charge per drop is consistent with the average charge per c.c. obtained with Simpson recorder. For the purpose of comparison we can take, as suggested by observations, the average radius of a rain-drop to be about 0·13 cm. and therefore about 100 drops to make 1 c.c. of rain. In making the comparison we must consider only those portions of the

TABLE V.

Charge on single drops.

Date.	Period.	Positive.				Negative.			
		Actual charge per drop by drop-recorder. (e.s.u.)	Charge per drop by Simpson receiver. (e.s.u.)	Ratio.	Amount of rainfall collected by the receiver in the interval. (c.c.)	Actual charge per drop by drop-recorder. (e.s.u.)	Actual charge per drop by Simpson recorder. (e.s.u.)	Ratio.	Amount of rainfall collected by the receiver in the interval. (c.c.)
	H. M. H. M.								
23rd June, 1932	18 50 to 19 00	0·023	0·021	1·1	2·5	..	..	..	..
23rd June, 1932	19 00 to 19 10	..	..	..	..	0·031	0·023	1·3	1·4
31st July, 1932	00 32 to 00 42	..	..	..	..	0·043	0·030	1·4	0·25
30th July, 1932	23 48 to 23 58	0·038	0·036	1·06	0·45	..	..	..	..
31st July, 1932	00 16 to 00 24	..	..	..	..	0·041	0·030	1·4	0·25
22nd July, 1932	08 44 to 08 52	0·039	0·039	1·00	2·90	..	..	..	..
29th Aug., 1932	18 50 to 19 00	..	..	..	..	0·050	0·032	1·6	2·03
29th Aug., 1932	18 22 to 18 26	0·030	0·024	1·3	0·66	..	..	..	..
			Mean	1·11			Mean	1·4	

TABLE VI.

Date.	Simpson recorder showing predominantly positive charge.			Date.	Simpson recorder showing predominantly negative charge.		
	Period.	No. of positive drops.	No. of negative drops.		Period.	No. of positive drops.	No. of negative drops.
	H. M. H. M.				H. M. H. M.		
10th July, 1932 ..	10 06 to 10 30	21	10	5th July, 1932 ..	22 18 to 22 30	6	25
10th July, 1932 ..	12 22 to 12 32	8	4	15th July, 1932 ..	08 00 to 08 24	7	20
15th July, 1932 ..	07 32 to 07 46	10	5	23rd June, 1932 ..	19 00 to 19 12	3	10
30th July, 1932 ..	23 26 to 23 46	18	12	25th July, 1932 ..	09 16 to 09 26	4	9
29th Aug., 1932 ..	18 20 to 18 38	14	6	25th July, 1932 ..	09 34 to 09 46	5	8
2nd Sept., 1932 ..	05 30 to 05 50	15	6	31st July, 1932 ..	00 08 to 00 20	1	12
2nd Sept., 1932 ..	05 50 to 06 10	14	7	29th Aug., 1932 ..	17 44 to 18 04	8	17
2nd Sept., 1932 ..	06 10 to 06 30	16	10	29th Aug., 1932 ..	18 42 to 19 04	5	26
2nd Sept., 1932 ..	06 30 to 06 44	9	3	4th Sept., 1932 ..	23 00 to 23 24	11	23
4th Sept., 1932 ..	21 22 to 21 38	14	8				

TABLE VII.

Non-thunder-storm Rain.

Relationship between the volume of a drop and its charge.

Date.	Period.	No. of drops.		Average volume per drop. (c.c.)	Average charge per positive drop. (e.s.u.)	Average charge per negative drop. (e.s.u.)
	H. M. H. M.	Positive.	Negative.			
31st July, 1932 ..	08 05 to 08 10	2	4	$3{\cdot}5\times10^{-2}$	0·067	0·098
25th July, 1932 ..	14 50 to 14 55	2	3	$3{\cdot}0\times10^{-2}$	0·033	0·042
15th July, 1932 ..	08 50 to 09 00	6	6	$2{\cdot}9\times10^{-2}$	0·037	0·026
25th July, 1932 ..	16 20 to 16 32	7	2	$2{\cdot}6\times10^{-2}$	0·032	0·036
15th July, 1932 ..	07 51 to 08 02	7	10	$2{\cdot}5\times10^{-2}$	0·042	0·048
25th July, 1932 ..	18 10 to 18 20	8	2	$2{\cdot}5\times10^{-2}$	0·130	0·001
25th July, 1932 ..	14 40 to 14 50	7	5	$2{\cdot}2\times10^{-2}$	0·031	0·031
25th July, 1932 ..	16 44 to 16 50	4	1	$2{\cdot}1\times10^{-2}$	0·036	0·031
15th July, 1932 ..	08 45 to 08 48	3	5	$2{\cdot}1\times10^{-2}$	0·054	0·066
31st July, 1932 ..	08 10 to 08 20	6	11	$2{\cdot}0\times10^{-2}$	0·169	0·105
15th July, 1932 ..	08 02 to 08 10	4	8	$1{\cdot}9\times10^{-2}$	0·093	0·153
15th July, 1932 ..	08 10 to 08 20	3	9	$1{\cdot}9\times10^{-2}$	0·162	0·094
15th July, 1932 ..	07 40 to 07 50	6	6	$1{\cdot}7\times10^{-2}$	0·078	0·129
31st July, 1932 ..	08 40 to 08 50	4	9	$1{\cdot}6\times10^{-2}$	0·157	0·158
31st July, 1932 ..	08 50 to 08 53	4	1	$1{\cdot}4\times10^{-2}$	0·118	0·214
31st July, 1932 ..	08 33 to 08 40	8	2	$1{\cdot}3\times10^{-2}$	0·097	0·095

Simpson records which show predominantly positive or predominantly negative charge; correspondingly the drop records must show a preponderance of positively charged drops or negatively charged drops. For, as both positively and negatively charged drops are present in the rain, the calculated average charge per c.c. from Simpson records must always be less than the average charge per c.c., if the drops which made the 1 c.c. of rain were either all positively or all negatively charged. It is only when we consider the portions which show high positive or negative charge that we can expect to get the nearest approach to charge per drop as actually recorded. The results of comparison for a few typical cases are given in Table V.

Since only selected portions of records have been used in preparing the above table, the results can only be regarded as qualitative.

It will be seen from the table that the charge of drops of rain as deduced from the Simpson records is always less than the average charge of drops given by the drop-recorder.

The relative proportion of positive and negative drops during periods when the Simpson recorder shows predominantly positive or predominantly negative charge can be seen from the figures given in Table VI.

TABLE VIII.

Non-thunder-storm Rain.

Date.	Period.	Rain-fall in mm.	Ratio of positive to negative drops.	Average charge per drop (from drop-recorder).		Average charge per c.c. (from Simpson recorder).	
				Positive. (e.s.u.)	Negative. (e.s.u.)	Positive. (e.s.u.)	Negative. (e.s.u.)
	H. M. H. M.						
23rd June, 1932 ..	19 30 to 19 40	9·0	0 : 5	..	0·034	0·005	0·250
2nd Sept., 1932 ..	05 40 to 05 50	7·2	8 : 5	0·041	0·039	0·018	..
2nd Sept., 1932 ..	06 10 to 06 20	7·1	10 : 3	0·044	0·056	0·010	..
23rd June, 1932 ..	19 20 to 19 30	4·2	3 : 7	0·030	0·048	0·079	0·038
2nd Sept., 1932 ..	05 50 to 06 00	3·8	7 : 4	0·044	0·086	0·172	..
22nd July, 1932 ..	09 00 to 09 10	3·0	3 : 6	0·027	0·041	0·006	0·004
2nd Sept., 1932 ..	05 30 to 05 40	2·9	6 : 2	0·044	0·054	0·007	..
2nd Sept., 1932 ..	06 20 to 06 30	2·5	7 : 7	0·027	0·041	0·043	..
15th July, 1932 ..	08 10 to 08 20	2·3	3 : 9	0·162	0·096	0·180	0·008
22nd July, 1932 ..	09 10 to 09 20	1·4	5 : 5	0·048	0·032	0·044	0·041
10th July, 1932 ..	10 30 to 10 40	1·2	6 : 2	0·055	0·035	0·034	0·008
2nd Sept., 1932 ..	06 30 to 06 40	1·0	6 : 0	0·038	..	0·091	..
10th July, 1932 ..	10 40 to 10 50	1·0	5 : 1	0·050	0·058	..	0·011
10th July, 1932 ..	11 20 to 11 30	0·9	8 : 2	0·045	0·059	0·031	0·009
2nd Sept., 1932 ..	06 00 to 06 10	0·8	7 : 2	0·052	0·078	0·20	..
22nd July, 1932 ..	08 50 to 09 00	0·7	6 : 7	0·058	0·026	0·047	..
10th July, 1932 ..	11 10 to 11 20	0·6	8 : 1	0·030	0·047	0·036	0·029
10th July, 1932 ..	10 20 to 10 30	0·5	7 : 4	0·051	0·054	0·045	..
23rd June, 1932 ..	19 10 to 19 20	0·5	3 : 5	0·033	0·045	0·040	0·206
30th July, 1932 ..	23 40 to 23 50	0·4	10 : 8	0·131	0·077	0·361	..
10th July, 1932 ..	10 00 to 10 10	0·4	4 : 1	0·039	0·047	0·081	..
2nd Sept., 1932 ..	06 40 to 06 50	0·3	6 : 2	0·042	0·084	0·125	..
15th July, 1932 ..	07 20 to 07 30	0·3	4 : 3	0·052	0·055	..	0·017
15th July, 1932 ..	07 30 to 07 40	0·3	7 : 6	0·061	0·068	0·043	..
10th July, 1932 ..	10 10 to 10 20	0·3	9 : 5	0·044	0·030	0·060	..
23rd June, 1932 ..	19 00 to 19 10	0·3	2 : 10	0·039	0·037	..	0·269

Table IX.

Thunder-storm Rain.

Date.	Period.	Rain-fall in mm.	Ratio of positive to negative drops.	Average charge per drop (from drop-recorder).		Average charge per c.c. (from Simpson recorder).	
				Positive. (e.s.u.)	Negative. (e.s.u.)	Positive. (e.s.u.)	Negative. (e.s.u.)
5th July, 1932 ..	21 20 to 21 30	16·8	8 : 12	0·063	0·053	..	0·120
5th July, 1932 ..	21 30 to 21 40	15·8	0 : 9	..	0·037	0·116	0·053
4th Sept., 1932 ..	21 20 to 21 30	9·7	10 : 5	0·055	0·058	0·013	..
4th Sept., 1932 ..	21 30 to 21 40	8·6	7 : 6	0·046	0·057	0·012	..
4th Sept., 1932 ..	21 40 to 21 50	8·6	8 : 5	0·027	0·062	0·023	..
4th Sept., 1932 ..	21 10 to 21 20	8·6	13 : 3	0·035	0·044	0·028	..
5th July, 1932 ..	22 20 to 22 30	4·6	6 : 19	0·041	0·069	..	0·078
4th Sept., 1932 ..	22 00 to 22 10	3·3	4 : 5	0·067	0·115	0·061	0·029
4th Sept., 1932 ..	22 10 to 22 20	2·4	7 : 2	0·063	0·084	0·074	0·039
4th Sept., 1932 ..	22 20 to 22 30	2·2	11 : 3	0·047	0·056	0·013	..
5th July, 1932 ..	22 00 to 22 10	1·7	10 : 16	0·031	0·047	..	0·042
4th Sept., 1932 ..	22 30 to 22 40	1·5	9 : 5	0·053	0·042	0·013	..
5th July, 1932 ..	22 10 to 22 20	1·4	6 : 21	0·076	0·041	0·050	0·075
5th July, 1932 ..	22 30 to 22 40	1·4	6 : 20	0·044	0·073	..	0·054
4th Sept., 1932 ..	21 50 to 22 00	1·3	6 : 9	0·028	0·040	0·047	..
4th Sept., 1932 ..	23 10 to 23 20	1·1	5 : 7	0·064	0·091	..	0·082
4th Sept., 1932 ..	22 40 to 22 50	1·0	5 : 6	0·099	0·082	0·032	0·059
4th Sept., 1932 ..	22 50 to 23 00	1·0	5 : 7	0·041	0·086	..	0·049
4th Sept., 1932 ..	23 00 to 23 10	0·9	3 : 12	0·059	0·052	..	0·080
5th July, 1932 ..	18 10 to 18 20	0·9	7 : 11	0·133	0·141	0·017	0·018
29th Aug., 1932 ..	17 30 to 17 40	0·9	7 : 10	0·032	0·038	..	..
5th July, 1932 ..	18 20 to 18 30	0·6	9 : 15	0·107	0·155	0·016	0·011
29th Aug., 1932 ..	17 40 to 17 50	0·5	3 : 10	0·040	0·045	0·109	0·090
5th July, 1932 ..	16 40 to 16 50	0·4	7 : 4	0·039	0·029	0·201	..
29th Aug., 1932 ..	18 50 to 19 00	0·4	2 : 12	0·033	0·050	..	0·272
5th July, 1932 ..	16 50 to 17 00	0·3	5 : 7	0·032	0·025	0·005	0·143
29th Aug., 1932 ..	18 20 to 18 30	0·3	9 : 4	0·026	0·027	0·180	0·256
29th Aug., 1932 ..	19 00 to 19 10	0·2	6 : 12	0·035	0·061	..	0·188
5th July, 1932 ..	22 40 to 22 50	0·2	8 : 13	0·076	0·079	0·384	0·305
29th Aug., 1932 ..	18 00 to 18 10	0·2	9 : 7	0·022	0·026	0·275	0·155
29th Aug., 1932 ..	19 20 to 19 30	0·2	10 : 7	0·028	0·015	0·024	0·035
29th Aug., 1932 ..	18 10 to 18 20	0·2	6 : 2	0·036	0·033	0·531	0·104

It will be seen from Table VI that when the rain has a predominantly positive charge, the number of positive drops is in considerable excess of the number of negative drops, being two or three times the latter, and when the rain has a predominantly negative charge, the disparity in some cases is still greater. It is important to note that scarcely the rain consists of drops which are all positively charged or all negatively charged.

The question whether the charge of a drop varies according to its size is rather difficult to settle.

Since the state of electrification of different clouds are different, the conditions under which the drops get electrified in different clouds are also different. Therefore, the charges of drops from one cloud are not strictly comparable with charges of drops from another cloud. Nonetheless, if the data be arranged in the order of sizes of the drops, we may be able to say whether in general the smaller sizes carry more or less charges than bigger sizes. Table VII gives a statistical analysis of the data.

In preparing Table VII certain periods have been taken in each of which the sizes of drops were more or less the same. The reason for doing this is that in practice it has been found very difficult to identify an individual drop whose size was noted by eye on the manometer with the corresponding displacement on the charge record, owing to the errors involved in noting down the time of successive drops, which was taken to the nearest half a minute. Moreover, when the drops were of very small size, the displacement on the manometer produced by an individual drop was very small, and consequently, on such occasions, the displacement produced by three or four successive drops was measured and the mean size of a drop determined.

It will be seen from Table VII that generally speaking the smaller drops have larger charge.

In order to find out whether the charge of a drop varies with the intensity of the rain, we have given in Table VIII the amount of rainfall recorded in intervals of 10 minutes and also the average charge per drop, positive and negative, during each of these intervals for non-thunder-storm rain. It will be seen that the charge per drop does not undergo any marked increase or decrease with decrease in the intensity of rain.

It is found that even though rainfall remains the same during consecutive intervals of 10 minutes the average charge per drop, positive or negative, undergoes wide variation. We see from the last two columns obtained from Simpson records, that as the rainfall becomes lighter and lighter there is a general tendency of charge per c.c. of rain to increase. We must, however, remember that as rain becomes lighter, the drops generally become smaller in size. Consequently in the same c.c. of rain, there will be more drops when the rain is light than when it is heavy. The general increase of charge per c.c. of rain as shown by the Simpson record would thus appear to be in no way inconsistent with the charge indicated by individual drops. Although the charge per drop shows generally no marked increase with decrease in the intensity of rain yet because the drops become smaller and smaller in size when the rain becomes lighter and lighter there is an intrinsic increase of charge when compared with some standard size of drops.

Similar features are shown by Table IX in respect of thunderstorm rain.

7. Theory of charge on rain-drops.

Simpson's 'breaking-drop' theory of the origin of electricity of rain is based on his experimental result showing that—

(1) breaking of drops of water is accompanied by the production of both positive and negative ions,

(2) three times as many negative ions as positive ions are released, thus leaving the drops charged positively.

TABLE X.

Date.	Period.	No. of drops.		Average volume per drop.	Average radius in mm.	Average charge per positive drop in e.s.u.	Average charge per negative drop in e.s.u.	Maximum charge by Rayleigh's formula in e.s.u.	Ratio positive.	Ratio negative.
	H. M. H. M.	Positive.	Negative.							
31st July, 1932 ..	08 06 to 08 10	2	4	$3{\cdot}5\times10^{-2}$	2·01	0·067	0·098	5·24	0·013	0·018
25th July, 1932 ..	14 50 to 14 55	2	3	$3{\cdot}0\times10^{-2}$	1·91	0·033	0·042	4·98	0·007	0·008
15th July, 1932 ..	08 50 to 09 00	6	6	$2{\cdot}9\times10^{-2}$	1·90	0·037	0·026	4·87	0·008	0·005
25th July, 1932 ..	16 20 to 16 32	7	2	$2{\cdot}6\times10^{-2}$	1·81	0·032	0·036	4·53	0·007	0·007
15th July, 1932 ..	07 51 to 08 02	7	10	$2{\cdot}5\times10^{-2}$	1·80	0·042	0·048	4·49	0·010	0·011
25th July, 1932 ..	18 10 to 18 20	8	2	$2{\cdot}5\times10^{-2}$	1·80	0·130	0·091	4·49	0·029	0·020
25th July, 1932 ..	14 40 to 14 50	7	5	$2{\cdot}2\times10^{-2}$	1·71	0·031	0·031	4·13	0·008	0·008
25th July, 1932 ..	16 44 to 16 50	4	1	$2{\cdot}1\times10^{-2}$	1·70	0·036	0·031	4·13	0·009	0·008
15th July, 1932 ..	08 45 to 08 48	3	5	$2{\cdot}1\times10^{-2}$	1·70	0·054	0·066	4·13	0·013	0·016
31st July, 1932 ..	08 10 to 08 20	6	11	$2{\cdot}0\times10^{-2}$	1·68	0·169	0·105	4·05	0·027	0·026
15th July, 1932 ..	08 02 to 08 10	4	8	$1{\cdot}9\times10^{-2}$	1·65	0·093	0·153	3·95	0·023	0·039
15th July, 1932 ..	08 10 to 08 20	3	9	$1{\cdot}9\times10^{-2}$	1·65	0·162	0·094	3·95	0·041	0·024
15th July, 1932 ..	07 40 to 07 50	6	6	$1{\cdot}7\times10^{-2}$	1·59	0·078	0·129	3·73	0·021	0·035
31st July, 1932 ..	08 40 to 08 50	4	9	$1{\cdot}6\times10^{-2}$	1·55	0·157	0·158	3·59	0·044	0·044

From the stage of cloud particles (of average diameter 7×10^{-4} cm.) to the stage of rain-drops (of average diameter 7×10^{-2} cm.), there is an increase of 10^6 times (or a million fold increase) in the volume of each particle. It is now generally agreed that only a small part of this increase can be due to condensation and the rest must be due to coalescence of particles.

While these experiments explain generation of charge on rain drops in those cases where this process of breaking is operative, we get no explanation as to why a drop which has been formed by coalescence of a large number of cloud particles, without breaking during coagulation, should be electrically charged. Simpson's breaking-drop theory, therefore, gives no insight into the general process of acquirement of charge by cloud particles.

Since in the initial stage, just when condensation has occurred in the cloud level, the particles of cloud suspended in the air may be regarded as colloids, the best method of approaching the problem is obviously to use the very large amount of knowledge that has been obtained in recent years in regard to the charge of colloidal particles.

Before we proceed to discuss this matter, it is important to remark that Lord Rayleigh (1882) has shown that a charged spherical drop must become unstable if Q^2 exceeds $16\ \pi a^3 T$ where Q is the charge, a the radius of the drop and T the surface tension. It is seen from this formula that the maximum charge possible on a drop of radius 0·1 cm. is 1·8 e.s.u. and on drop of radius $\frac{1}{8}$ cm. 9·6 e.s.u.

It will be seen from Table X that the ratio of the actual charge to the maximum possible charge varies from $\frac{1}{1000}$ to $\frac{1}{25}$. We also see that the ratio shows a general increase with decrease in the size of the drops. When we analyse the charges in the rain-drops as determined by the experiments described in this thesis and compare them with those on oil drops as found by Millikan in his classical experiments, we get indirect evidence that the origin of charge on rain-drops is more fundamental than is postulated by Simpson's theory.

The average radius of Millikan drop is 2×10^{-4} cm. Millikan found that the number of ions in a drop varies from 1 to 130, the common value being about 10. Assuming that a rain-drop of radius 10^{-1} cm. has grown by coagulation of Millikan drops, its charge will be

$$0{\cdot}06\ N \text{ e.s.u.}$$

where N represents the number of ions in a Millikan drop. Taking N to be 10, we find the charge to be equal to 0·6 e.s.u. Actually, however, the charge on a drop is $\frac{1}{10}$ of this amount or less. The charge could have been 0·6 e.s.u. if all the drops that coalesced carried charges of the same sign. But since they would not necessarily be of the same sign, the charge should be expected to be less than 0·6 e.s.u.

We proceed now to find whether on the assumption that the cloud particles are all initially colloidal particles, the observed charge on the rain-drops will be accounted for. That the growth of rain-drops can occur by coalescence of minute particles of water, all electrically charged, is confirmed by Lord Rayleigh's experiments (1878-79).

Now, the experiments on the cataphoresis phenomena show that the majority of the colloidal particles are negatively charged when they are suspended in water. This is in agreement with the rule that when two substances are electrified by friction the substance with the higher dielectric constant takes on a positive charge (Lewis, *A system of Physical Chemistry*, Vol. I, p. 334, 1924). The same law would indicate that the majority of water particles suspended in air should be positively charged in the same way as air bubbles in water should be negatively charged and this is what has actually been found by Alty (1924, 1926).

The charge E on a colloidal water particle suspended in air will be given by the well-known formula

$$E = V\frac{R^2}{D}K$$

where V is the potential difference between the water particle and the air in contact with it, K is the dielectric constant of air, D the thickness of the Helmholtz electrical double-layer, which is supposed to be small compared with R the radius of the particle.

Taking

$$V = \frac{0{\cdot}031}{300} \text{ e.s.u.}$$

$$R \quad 0{\cdot}001 \text{ cm.}$$

$$D \quad 5\times10^{-8} \text{ cm.}$$

$$K \quad 1 \text{ for air}$$

$$E = \frac{0{\cdot}031}{300}\times\frac{(10)^{-6}}{5\times10^{-8}}$$

$$= 2\times10^{-3} \text{ e.s.u.}$$

In connection with cataphoresis it is necessary to realise that the movement of the colloidal particle in an electric field is only made possible by the fact that there is a certain slip or 'give between the two coatings of the double electrical layer'. If the charges were fixed the particles as a whole would have no effective charge and would therefore remain motionless in the electric field. The final stage in cataphoresis must be, therefore, a polarisation of the colloid-medium system, followed by a transfer of charge on the layer made up of the molecules of the medium, to other contiguous molecules.

Another point of view is that the charge is due to the unequal adsorption of the ions of electrolytes by colloidal particles. Those ions which are adsorped in larger quantity owing to their higher adsorption potential, form the charging ions (aufladende ionen according to Pauli), their partners remaining in larger amount in the intermicellar liquid as compensative ions (Gegenionen of Pauli). The excess of one kind of ions on the surface determines the sign of the charge and its density.

In the early stage after condensation has taken place on nuclei and a cloud has formed, the growth of drops may be expected to take place under the laws which govern the coagulation of colloidal particles. It is known that on addition of a very small quantity of electrolytes (ions) to suspensions, emulsions or colloids the corresponding substances are thrown out of solution. The operation seems to be of a physical nature. Hardy-Schulze's law makes the important generalisation that ions carrying a sign opposite to that carried by the colloid are the most active precipitants, and at the same time the higher the valency of the ions (i.e. the greater the number of unit charges upon it) the greater is its precipitating action. In the atmosphere, gaseous ions are present in such large numbers that it is not difficult to imagine their precipitating action on colloidal cloud particles.

Experiments with a Wilson Condensation Chamber under ordinary temperature (15° C. to 30° C.) and expansion ratios 1·05 to 1·3 shows that as soon as the cloud has formed, the particles have diameters varying from 4 μ to 10 μ. The colloidal water particles suspended in air is therefore of slightly larger diameter than the colloidal particles suspended in water. On the other hand, coronae measurements indicate that in cloud suspended in air, the particles have diameters varying from 2 μ to 12 μ, while the diameters of fog droplets is on the average 5 μ.

This process of coagulation by oppositely charged ions will undoubtedly be accompanied by a reduction in charge of the drop that would be obtained by simple addition law. A rain-drop of a radius 0·1 cm. which has grown by coagulation of particles of radius 0·001 cm. will contain 10^6 such particles.

Since each particle has a charge of 2×10^{-3} e.s.u. the total charge on the rain-drop, if all the particles which formed it had charges of the same sign, will be 2×10^3 e.s.u. Actually, however, we find that the charge on a rain-drop is considerably

smaller than this amount. The decrease during coagulation is obviously due to loss of charge in various ways, one of which is the coagulation of oppositely charged drops and the other is the loss of charge due to encounter with oppositely charged ions.

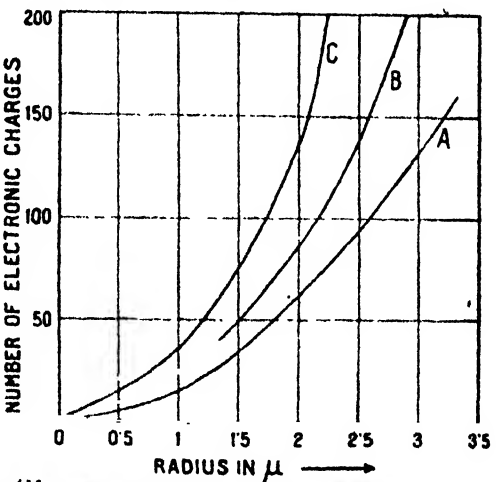
It has been pointed out by Robonitch and Kergin (1935) that adsorption of ions of opposite sign to the colloidal particle is one of the main factors in diminishing the stability of the colloid and causing its coagulation. When ions of higher valency, of larger specific adsorption potential, than the initial compensating ions are adsorped, they enter the inner part of the outer component of the double-layer. This diminishes the number (density) of electric charges on the boundary between the liquid moving with the particle and the rest of the liquid and consequently the electro-kinetic or ζ-potential on this surface. The latter being more or less accurate quantitative measure of repulsive forces between particles, these forces decrease too, and the stability of the system breaks down.

With regard to the kinetics of the charging process, Panthenier and Moreau Hanot (1936), have shown that when the particle is so large that the effects due to diffusion of the ions towards the particle, and to mirror forces, can be neglected, the kinetics of the charging of a spherical dielectric particle can be expressed by the following equation (assuming that each ion striking the surface of the part gives up its charge):

$$Q = \left(1 + 2\frac{K-1}{K+2}\right) Ea^2 \left(\frac{\pi u n \epsilon t}{1+\pi u n \epsilon t}\right),$$

where Q is the charge acquired by the particle in the time t, a the radius, k the dielectric constant of the particle, E the strength of the external electric field, n the number of ions per c.c., u their mobility, and ϵ the electronic charge.

In the work of J. P. Gott, the ionic atmosphere was produced by means of X-rays, water drops of 4·4 mm. diameter were used, and the initial rate of charging was determined. The experiments of Fuchs, Petrjanoff and Rotzieg (1936) with oil drops gave results which are given in Fig. 11.



'A' t = 0·0165 sec., unee = 3·18 A/SQ. cm.
E = 556 V/cm., n = 1·98 X 10^7/ cc.

'B' t = 0·0172 sec., unee = 5·51 A/SQ. cm.
E = 732 V/cm., n = 2·70 X 10^7/ cc.

'C' t = 0·015 sec., unee = 9·1 A/SQ. cm.
E = 940 V/cm., n = 3·4 X 10^7/ cc.

FIG. 11.

This shows that as the field strength increases there is a rapid increase in the rate of charging.

8. Conclusion.

The general agreement of charge on a rain-drop obtained by the above-mentioned consideration with that actually observed would suggest that the process is operative in the atmosphere on a large scale. Besides the growth of charge by coagulation of colloidal particles, the capture of ions by formed water drops in a pre-existing electrical field in the way described by Gott will lead to a general increase of charge up to a certain limit and whenever the vertical motion is of such an order as to break the drops, the charge will be further augmented by the Simpson process.

A method of coagulation due to the relative rates of fall of cloud particles of different sizes, which has been worked out by Findeisen, Langmuir and others, must be in operation on a large scale in a developing cloud. Findeisen's analysis (1937, 1938, 1939) shows that drops of size 2×10^{-2} cm. would fall from a cloud of about 200 m. thick, 8×10^{-2} cm. from a cloud 1,000 m. thick and 14×10^{-2} cm. from a cloud 2,000 m. thick. Langmuir (1948) has worked out how accretion takes place by collision, taking due account of aerodynamic flow. Since coagulation is the main process by which cloud particles grow into rain-drops, it is no wonder that in a raining cloud, there is a mixture of both positively and negatively charged drops.

9. Summary.

During the years 1930–32, an apparatus was maintained in continuous action in the Colaba Observatory, Bombay, for recording the electric charge on individual drops of rain. A drop of rain in order to have access into the insulated receiver has first to pass through a fixed but adjustable cylindrical opening of average diameter 1·4 cm. and then through a second opening of diameter 2·4 cm. at the periphery of a rotating disc. Both openings are provided with trap arrangements so that a drop striking the sides is caught and led away. The period of rotation of the disc is so adjusted that with moderate intensity of rain a second drop may not enter into the receiver until the charge of the first has been recorded and the system earthed by an automatic device. A glass manometer of very fine bore is attached to the receiver and keeps a record of the size and number of drops.

For recording the charge given to the receiver by a drop of rain, a Wilson tilt electroscope is used very nearly at its maximum sensitiveness, and the movement of the gold-leaf is photographed by allowing light from a point source to pass through a minute slit and a short focus lens and fall transversely as a narrow beam of about half the breadth of the leaf over a fine pin-hole made at its lower end, which is twisted at right angles to its plane. The transmitted light through the hole gives a magnified image of its displacement on a quickly moving photographic paper. All necessary precautions were taken to avoid the influence of the field of the earth and any artificial field on the drops.

This method of recording is of particular interest in view of the fact that the Wilson tilt electroscope has not to our knowledge been used in the past as a recording instrument. Simultaneously with the above apparatus, a Simpson apparatus giving the charge of rain collected every two minutes was kept in action. In 1934, observations were repeated at Poona with an independent arrangement in which a Lindeman electrometer was used. Potential gradient was also continuously recorded using a ionium collector.

An analysis of the records shows that both positively and negatively charged drops are present in the rain received from any part of the cloud. When the rain received during any interval is positively or negatively charged as a whole, there is an excess of positively or negatively charged drops. The mean charge of positive drops is 0·021 e.s.u. in non-thunder-storm rain and 0·051 in thunder-storm rain, the mean charge of negative drops is 0·023 e.s.u. in non-thunder-storm rain and 0·057 e.s.u. in thunder-storm rain.

A detailed analysis of the observations lend support to the view that initially the cloud particles develop charge in exactly the same way as colloidal particles or particles floating in a medium and capturing ions. The breaking of drops by the Simpson process or the striking of one particle against another tends to augment the charge after they have grown to a certain size.

When the cloud extends to heights considerably above the freezing level so that the cloud particles get frozen into ice-particles, the striking of the ice-particles against each other will make them negatively charged.

The experiments were continued at Poona in 1935 and 1936, in which a Lindeman electrometer was used instead of the Wilson tilt electroscope. As each drop entered the receiver, the charge recorded was read through the microscope.

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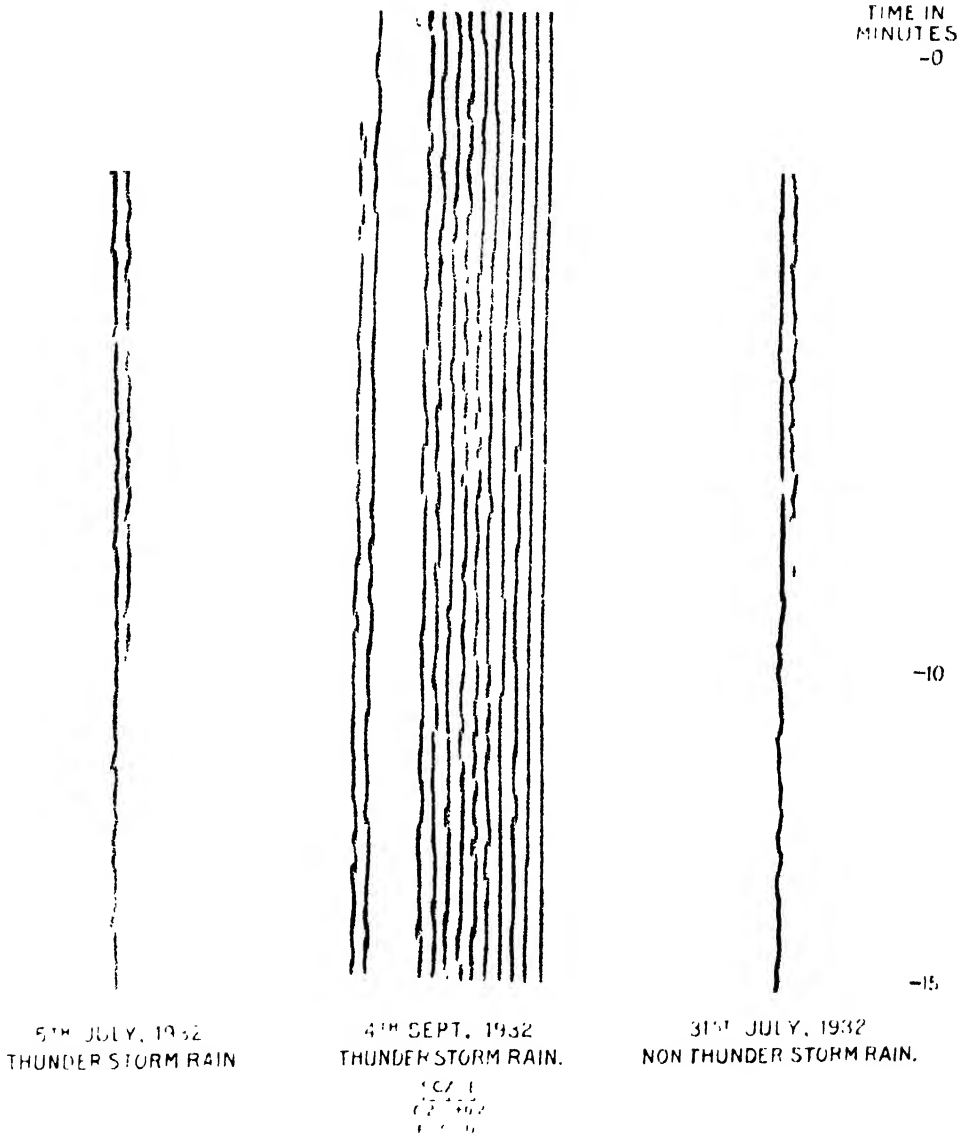

Portion of a record of the charges of Thunder storm rain drops.

SKELETON OF CYPRINOID FISHES IN RELATION TO PHYLOGENETIC STUDIES.

PART I. SYSTEMATIC POSITION OF THE GENUS *Gyrinocheilus* VAILLANT.

By L. S. RAMASWAMI, *Senior Research Fellow, N.I.S.I., Department of Zoology, Central College, Bangalore.*

(Communicated by Dr. S. L. Hora, D.Sc., F.N.I.)

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INTRODUCTION.

In his monograph on the family Homalopteridae, Hora (1932) after examining the external and a few skeletal characters recorded that the members comprising the family may have been polyphyletic in their origin and that the external or superficial resemblances were due to convergence on account of their life in torrential waters. Further, he divided the family tentatively into the Homalopterinae and Gastromyzoninae and derived the two subfamilies from cyprinid and cobitid ancestors respectively.

It occurred to me that a study of the cranial osteology of a few genera of the family might give us a better insight into the classification of these forms and accordingly, I studied and published (Ramaswami, 1948) an account of the skull structure of *Bhavania*, *Balitora* and *Gastromyzon*. At the time, I was not in a position either to confirm or disprove the polyphyletic origin of the Homalopteridae since I had not examined the cyprinid and cobitid genera which have been regarded as the possible ancestors.

However, the award of a senior research fellowship of the National Institute of Sciences of India has made it possible for me to devote uninterruptedly to an examination of the skeletal structures of the members of the Ostariophysi more thoroughly. The material for this study has been partly made available to me by the Director, Zoological Survey of India, to whom I am deeply thankful and has also been partly collected by me during my specimen collection tours. I also propose to examine a few foreign genera as and when material becomes available.

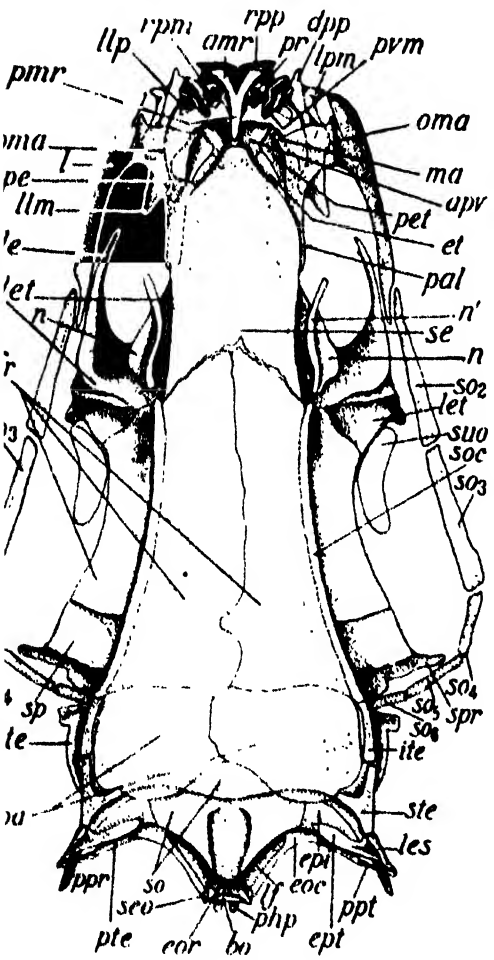
The results of my observations will be published in a series of papers and the skull of *Gyrinocheilus kaznakoi* Berg will form the theme of the first paper.

The systematic position of *Gyrinocheilus* was till recently unsettled; it was referred to the subfamily Homalopterinae by Vaillant and later Regan (1911) pointed out that to make it a type of a separate family or subfamily would be to obscure its cyprinid relationship and placed it next to *Crossocheilus* and *Garra* (*Discognathus*) in the Cyprinidae. Hora (1923), however, by a study of the external characters of the fish, while admitting the similarities between *Crossocheilus* and *Garra* on the one hand and *Gyrinocheilus* on the other, erected the family Gyrinocheilidae to accommodate it, a procedure also adopted by Berg (1940).

Popta (1906) described a fish *Paracrossocheilus bicornis* from Borneo showing greater similarities to *Gyrinocheilus* than to either *Garra* or *Crossocheilus*; however, have not been able to study this fish on account of the paucity of material.

Observations.[1]

The ethmoid region : In the skull of *Gyrinocheilus*, the ethmoid is a prominent bone and the supraethmoid portion (figs. 1, 2, *se*) is particularly broad and articulates immovably with the frontals (fig. 1, *fr.*) as in the Cyprinidae and Catostomidae. In *Garra* (fig. 3, *se*) it is wider than long as seen in the dorsal aspect and the prevomer (figs. 3, 4, *apv*) extends considerably in front of it as a projection. In *Crossocheilus* (fig. 5, *se*) it is not so broad as in *Garra* leaving a small gap between the two prevomerine projections. In *Gyrinocheilus* the prevomerine extensions (figs. 1, 2, *apv*) are in the form of long anterior processes, one on either side of the posterior process of the median rostral (*pmr*). Articulating on either side of the ethmoid (figs. 1–6, *et*) and the prevomer (*pv*) in *Gyrinocheilus*, *Garra* and *Crossocheilus* there is a pre-ethmoid (*pet*) with a rounded facet for articulation with the palatine (*pal*).



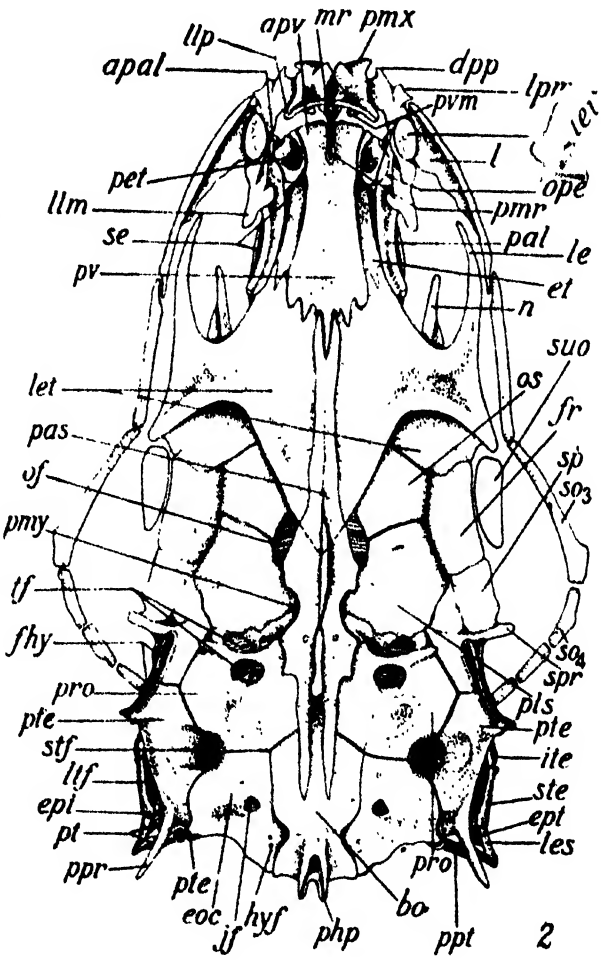


Fig. 1. Skull of *Gyrinocheilus kaznakoi* Berg. Dorsal aspect.
Fig. 2. Skull of *G. kaznakoi* Berg. Ventral aspect: the pterotic region is tilted to show the lateral temporal fossa.

In front of the ethmoid is the median rostral (figs. 1–6, *mr*) and in *Gyrinocheilus* the rostral shows a long median process (figs. 1, 2, *pmr*) extending between the two

[1] All figures have been drawn at a magnification of × 17 (approx.), except figures 10–12*a*.

prevomerine extensions and anteriorly an expanded portion (fig. 1, *amr*) which comes in contact ventrally with the rostral process (*rpp*) of the premaxilla. The posterior portion of the median rostral also shows a winglike expansion on either side very near to where it expands. In *Garra* the two ends of the median rostral (figs. 3, 4, *mr*) are rounded and in the middle there is a dorsomedian projection (*dmp*); in *Crossocheilus* the middle portion shows two prominent lateral projections (fig. 5, *dlp*).

In *Gyrinocheilus*, as already said, the premaxilla shows a short but broad rostral process (fig. 1, *rpp*) and the lateral limb (*pp*) is exceedingly short. In *Garra* and *Crossocheilus* there is an elongated limb of the premaxilla towards the rostral (figs. 3–6, *rpp*) and the lateral limb (figs. 4, 6, *llp*) is short (*Crossocheilus*) or long (*Garra*).

The maxilla in *Gyrinocheilus* shows as in the Cyprinidae a premaxillary process (figs. 1, 2, *dpp*), a ventral rostral process (*rpm*), a posteriorly directed facet (*pvm*) towards the prevomer and a lateral process (*lpm*) for the attachment of the adductor mandibulae ligament. In *Garra* (figs. 3, 4) and in *Crossocheilus* (figs. 5, 6) while the above processes are noticed, however, from the posterior face of the maxilla, there are two articular facets: one (*pvm*) directed towards the prevomer and the other (*pam*) towards the palatine.

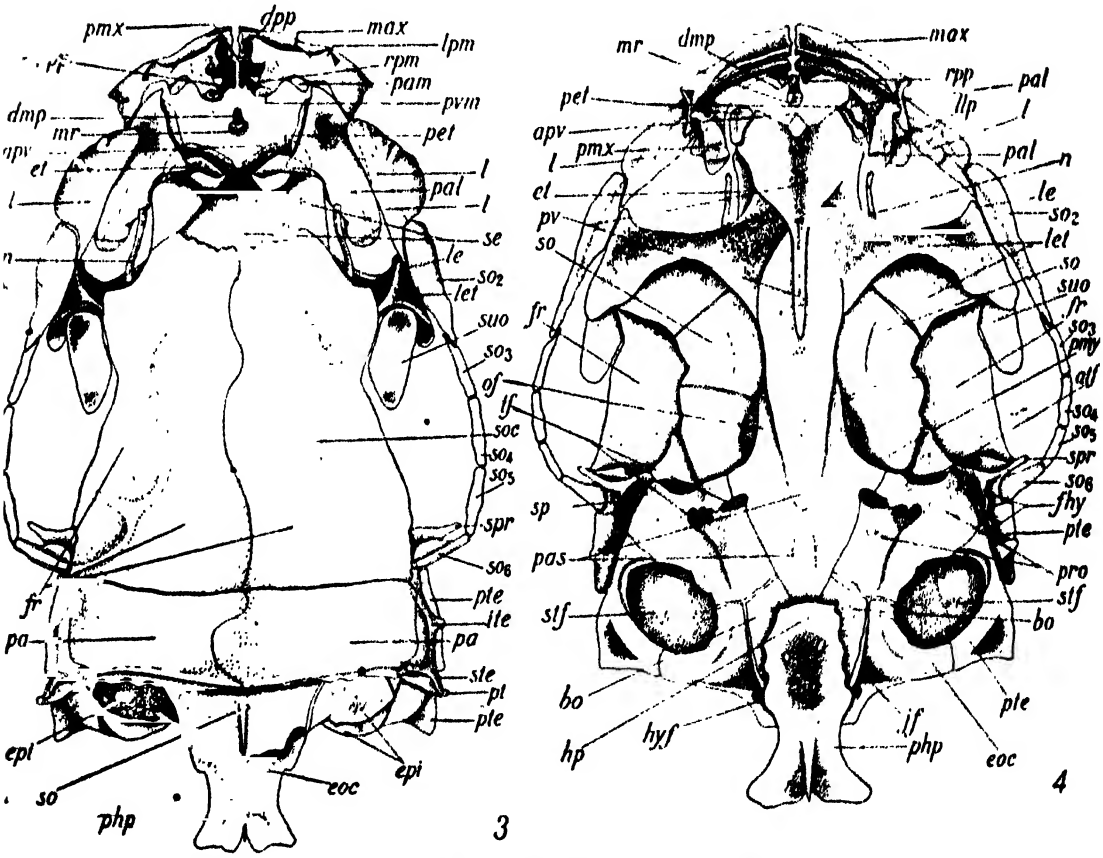


FIG. 3. Skull of *Garra mullya* Sykes. Dorsal aspect: the maxillae are pulled to show the processes.

FIG. 4. Skull of *G. mullya* Sykes. Ventral aspect: the bony process for the horny pad is incomplete.

The lateral ethmoid (figs. 1–6, *let*) is a fairly large bone on either side of the ethmoid-frontal; in *Gyrinocheilus* the bone shows a long lacrimal process (figs. 1, 2, *le*) and opposite this, there is a short projection from the lateral ethmoid.

Mesially, the two lateral ethmoids extend posteriorly far into the optic foramen (fig. 2, *of*) dorsally to the parasphenoid (*pas*), a feature not noticed in any other cyprinid fish studied by me. While in *Garra* (figs. 3, 4, *le*) the lateral processes referred to above are diminutive, they are feebly developed in *Crossocheilus*.

Flanking the lateral ethmoid in *Gyrinocheilus*, *Garra* and *Crossocheilus* there are five or six suborbital bones (figs. 1–6, *so1–so6*), the anteriormost of which is usually called the lacrimal (*l*). In *Gyrinocheilus*, the lacrimal may represent a united lacrimorostral or a lacrimojugal.

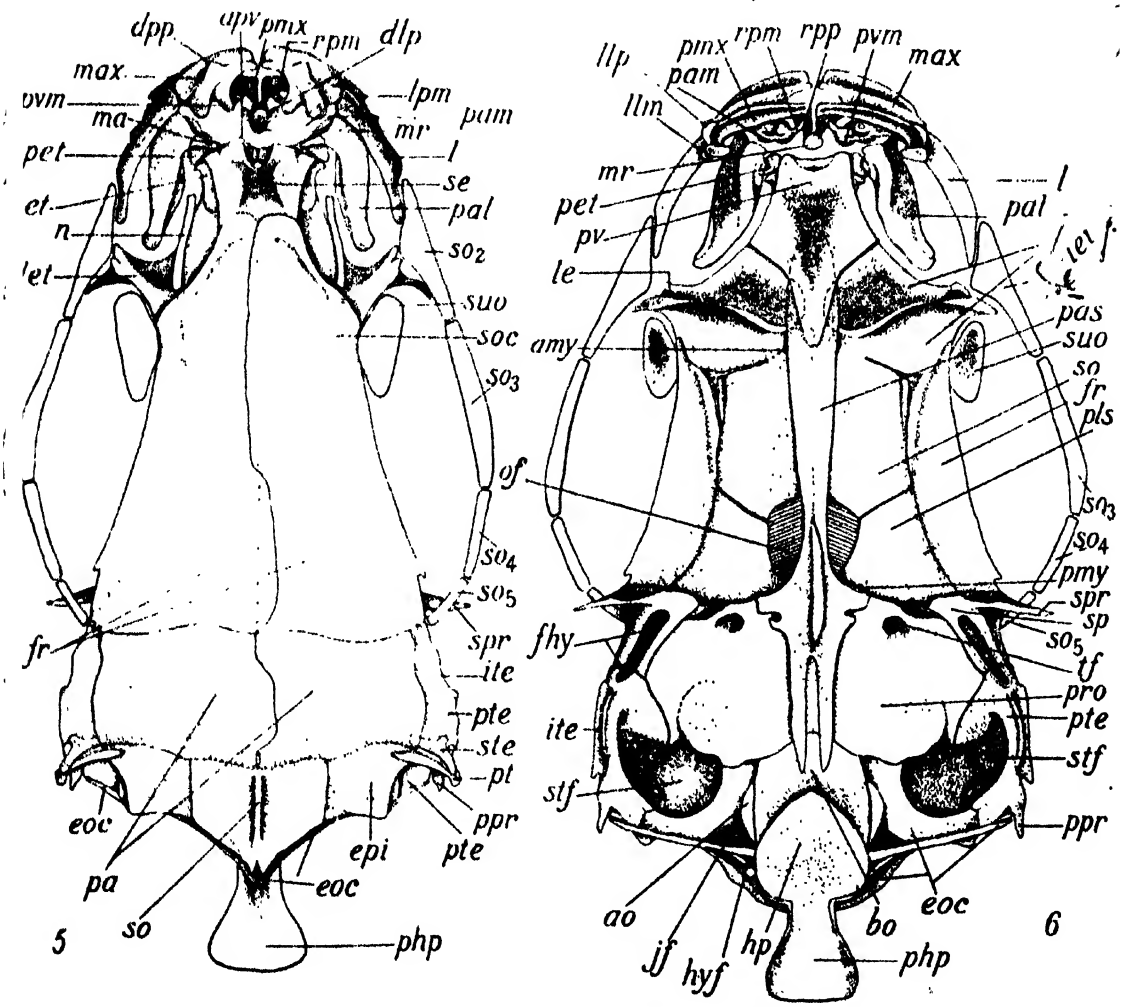


Fig. 5. Skull of *Crossocheilus latius* (Ham.). Dorsal aspect.
Fig. 6. Skull of *C. latius* (Ham.). Ventral aspect.

Ventrally, the shape of the prevomer differs in the three genera; in *Gyrinocheilus* the prevomer (fig. 2, *pr*) extends anteriorly in the form of two processes (*apv*) with an indentation in between in which, as already said, the posterior limb of the median rostral (*pmr*) is seen. The posterior portion of the prevomer is broad and a very tiny projection of it lies ventrally to the parasphenoid (*pas*). In *Garra* the anterior portion of the prevomer (fig. 4, *pr*) spreads out (*apv*) and there is a long postero-

median portion; in *Crossocheilus* while the anterior portion of the prevomer (fig. 6, *pv*) is not so broad as in *Garra*, there is a blunt posterior portion.

The orbitotemporal region: The supraorbitals (figs. 1-6, *suo*), the frontals (*fr*) with the supraorbital sensory canal (*soc*) in them, the four (*Crossocheilus*) or five (*Gyrinocheilus* and *Garra*) suborbital bones excluding the lacrimal, the large orbitosphenoids (figs. 2, 4, 6, *os*, *so*) and the pleurosphenoids (*pls*) and the anterior extension of the parasphenoid dorsally to the prevomer are all common to the three genera studied. Generally in the Cyprinidae, not much variation is noticed in the bones of this region.

The interorbital septum in some cyprinids (e.g. *Labeo*) is formed by a ventromedian portion of the two orbitosphenoids coming in contact with a dorsomedian portion of the parasphenoid in front of the optic foramen. In *Garra* and *Gyrinocheilus* the two orbitosphenoids are wide apart and thus there is no interorbital septum; in *Crossocheilus* however, the orbitosphenoids and the parasphenoid form a typical septum.

In each eyeball, there are two cup-shaped sclerotic bones.

The auditory region: The sensory canal does not pass through independent ossicles in this region as in the orbital. On the dorsal aspect of the pterotic region of *Garra* and *Crossocheilus*, the sensory canal in the intertemporal ossicular region (figs. 3, 5, *ite*) passes in the pterotic bone like the supraorbital canal in the frontal. Posteriorly, there is also a triradiate canal connecting the temporal and the occipital canals and leading to the lateral line; the lateral limb of this is very small. This is the supratemporal ossicular region. Similarly in *Gyrinocheilus* leading from the supraorbital canal, the temporal canal passes in the pterotic probably representing the intertemporal of other forms while posteriorly, in the same bone, it passes through the Y-shaped supratemporal (*ste*) region. The supratemporal establishes contact with the occipital sensory canal mesially and anteriorly with the temporal canal and posteriorly with the lateral line ossicle (*les*) on the post-temporal. In these features *Gyrinocheilus* resembles the cyprinids closely.

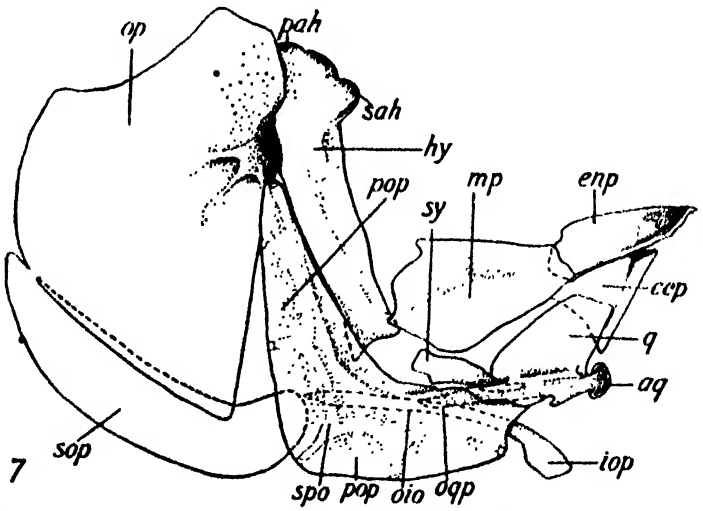


FIG. 7. Lateral aspect of the right upper jaw and opercular bones without the palatine of *Gyrinocheilus kaznakoi* Berg.

On the ventral aspect, the sphenotic (figs. 2, 4, 6, *sp*) and the pterotic (*pte*) show articular facets for the hyomandibula (*fhy*) in all the three genera examined and peculiarly in *Gyrinocheilus* (figs. 1, 2) and *Crossocheilus* (figs. 5, 6) the pterotic shows a spinelike process (*ppr*) posteriorly.

The prootic shows in *Gyrinocheilus*, *Garra* and *Crossocheilus* the orifices (figs. 2, 4, 6, *lf*) for the exit of the branches of the fifth and seventh cranial nerves. Similarly in all the three examples, the external opening of the posterior myodome (*pmy*) is noticed between the lateral limb of the parasphenoid and the dorsally lying pleurosphenoid; in addition an anterior myodome (fig. 6, *amy*) is also noticed in *Crossocheilus*.

In *Gyrinocheilus*, there is a large lateral temporal fossa (fig. 2, *ltf*) bounded mesially by the epiotic (*epi*) and the pterotic (*pte*), posteriorly by the epiotic and anteriorly by the pterotic. Dorsally there is the parietal (*pa*) and forming the edge of the latter, the pterotic with the intertemporal (*ite*) and supratemporal (*ste*) are present. The subtemporal fossa (*stf*) projects into the fossa above. A lateral temporal fossa is absent not only in *Garra* and *Crossocheilus* but also in the other cyprinids studied by me.

The shallow subtemporal fossa referred to above is formed by the three bones, viz., the prootic, the pterotic and the exoccipital in *Gyrinocheilus* (fig. 2, *stf*); in *Garra* (fig. 4) and *Crossocheilus* (fig. 6, *stf*) it is large and is bounded by the prootic, the epiotic, the pterotic and the exoccipital.

The exoccipitals (fig. 1, *eoc*) in *Gyrinocheilus* do not extend dorsally and form the roof for the foramen magnum posterior to the supraoccipital as in the case of *Garra* (fig. 3, *eoc*) and *Crossocheilus* (fig. 5, *eoc*). They also do not show a fontanel as in the cyprinid examples. However, between the supraoccipital (fig. 1, *so*) and the exoccipital (*eoc*) on either side of the foramen magnum, there is a large gap (*lf*) very suggestive of a reminiscent fontanel in *Gyrinocheilus*.

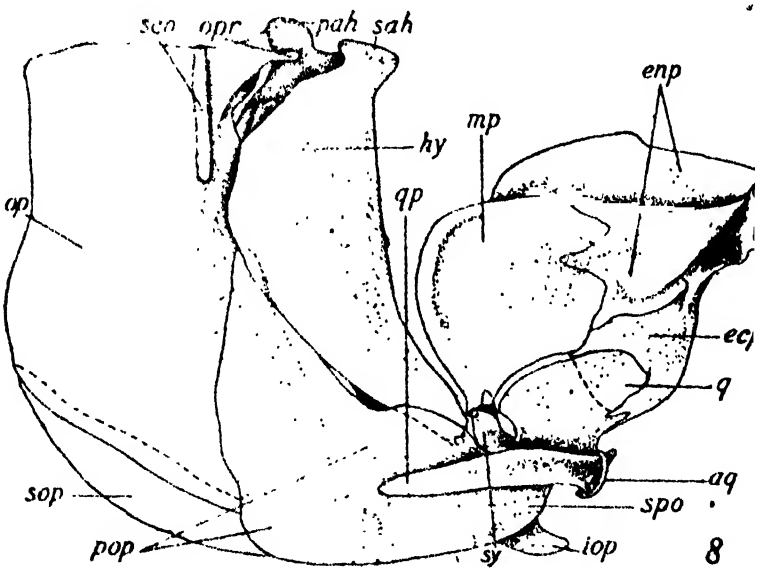


FIG. 8. Lateral aspect of the right upper jaw and opercular bones, without the palatine of *Garra mullya* Sykes.

Further, as in the Cyprinidae and the Cobitidae each exoccipital in *Gyrinocheilus* gives rise to a projection mesially (fig. 1, *eor*) and between the projections of the exoccipital and the dorsal aspect of the basioccipital (*bo*) is the recess for the sinus impar which opens posteriorly by an orifice (*seo*) in each exoccipital.

The basioccipital in *Gyrinocheilus* (fig. 2, *bo*) shows only two posterior projections (figs. 1, 2, *php*) which do not unite below the dorsal aorta; in *Garra* and *Crossocheilus* (figs. 4, 6, *php*) there is a well developed pharyngeal process extending below the aorta and also an anteriorly expanded plate (*hp*) for the attachment of a horny

pad. The absence of such an anterior projection for the attachment of a horny pad in *Gyrinocheilus* has already been noted by Regan (1911).

The supraoccipital (fig. 1, *so*) roofs the foramen magnum in *Gyrinocheilus* and between it and each exoccipital, as already noted, there is a large gap (*lf*).

The upper jaw: The upper jaw shows the characteristic bones, viz., the hyomandibula (figs. 7, 8, 9, *hy*), the metapterygoid (*mp*), the entopterygoid (*enp*), the ectopterygoid (*ecp*), the quadrate (*q*) with its posterior process (*qp*), the symplectic (*sy*), the preopercular (*pop*) and the other opercular bones (*op*, *iop*, *sop*) associated with it in all the three genera *Gyrinocheilus*, *Garra* and *Crossocheilus*. The preopercular (figs. 7, 8, 9, *pop*) is large showing the passage of the sensory canal (*spo*) in it. While in these features there is close similarity of the upper jaw bones in the three genera, there are however, some important differences. The opercular of *Garra* (fig. 8, *op*) and of *Crossocheilus* (fig. 9, *op*) shows a large sensory canal (*sco*) which connects the temporal and the preopercular canals. There is also a prominent process (*opr*) given off from the opercular towards the hyomandibula near the latter's pterotic articular facet; the opercular of *Gyrinocheilus* (fig. 7, *op*) does not show these two features. The posterior limb of the quadrate in *Gyrinocheilus* (*oqp*) is mesially lodged in a groove of the preopercular while in *Garra* (fig. 8, *qp*) and *Crossocheilus* (fig. 9, *qp*) the posterior process of the quadrate is lateral to the preopercular (*pop*).

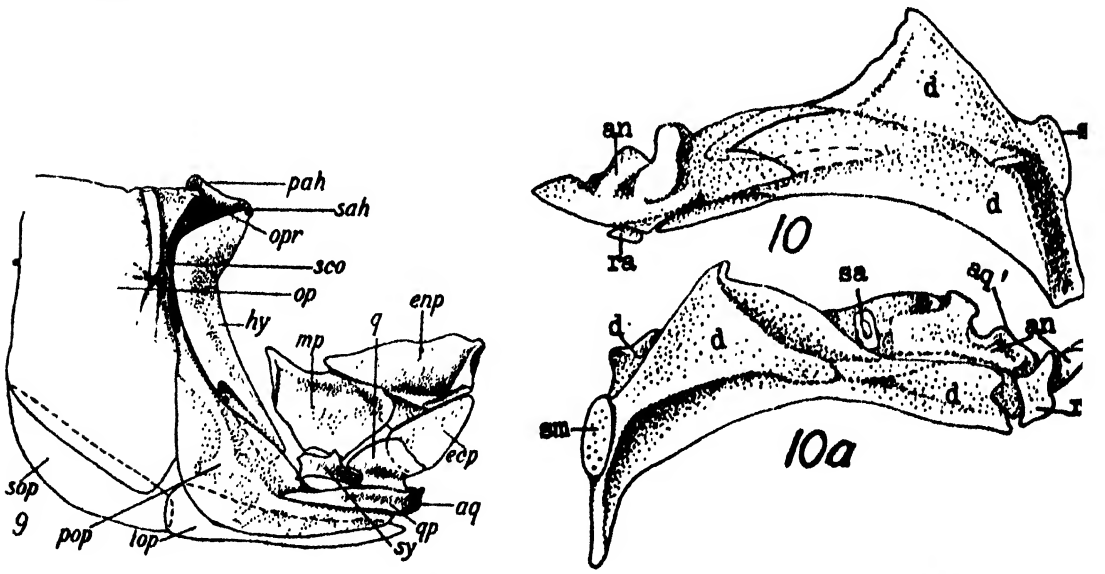


FIG. 9. Lateral aspect of the right upper jaw and opercular bones, without the palatine of *Crossocheilus latius* (Ham.).

FIG. 10. Lateral aspect of the right ramus of the lower jaw of *Gyrinocheilus kaznakoi* Berg.

FIG. 10*a*. Mesial aspect of the same.

The lower jaw: As in *Garra* (fig. 11) and *Crossocheilus* (fig. 12), the lower jaw of *Gyrinocheilus* (fig. 10) shows the four bones, viz., the dentary (*d*), the angular (*an*), the sesamoid angular mesially (*sa*), and the retroarticular (*ra*), the last being a cartilage bone. In *Garra* (fig. 11) and *Crossocheilus* (fig. 12) the dentary and the angular show the passage of sensory canals (*scd*, *asc*) in them; in *Gyrinocheilus* (fig. 10) the passage of the canal was not clear. There is not much difference between the lower jaw of *Gyrinocheilus* and that of the Cyprinidae except however, in the shape of the bones.

The hyobranchial apparatus: The hyobranchial apparatus of *Gyrinocheilus* shows many interesting features. There is a median basihyal (fig. 13, *bh*) lying dorsally to the two pairs of hypohyals (hh_1, hh_2); there are four median bony copulae

(cop_1–cop_4) representing the united basibranchials. As pointed out by Vaillant (1902) there are two pairs of gillrakers on the dorsal aspect of each branchial arch and these rakers extend in double rows on the dorsal aspect of the median copulae also. There are only *two* pairs of hypobranchs (hb_1, hb_2) in connexion with the first two branchial arches. In the cyprinid examples studied by me and in the Cyprinidae in general, there are uniformly the first three pairs of hypobranchs, the last two pairs of branchial arches being devoid of them. There are three pairs of pharyngobranchs (pb_1, pb_2, pb_3) in *Gyrinocheilus* representing the first, the second and probably the fused third and fourth pharyngobranchs. The fifth pair of ceratobranchs (cb_5) is thin and slender and is devoid of teeth unlike what is noticed in the cyprinid examples studied. The parahyoid is attached to the basihyal by means of two processes while posteriorly it shows a winglike expansion resembling the cyprinid one. Thus in the possession of two hypobranchs, four copulae, three pharyngobranchs and the edentulous fifth pair of ceratobranchs, the hyobranchial apparatus of *Gyrinocheilus* differs from that of the Cyprinidae.

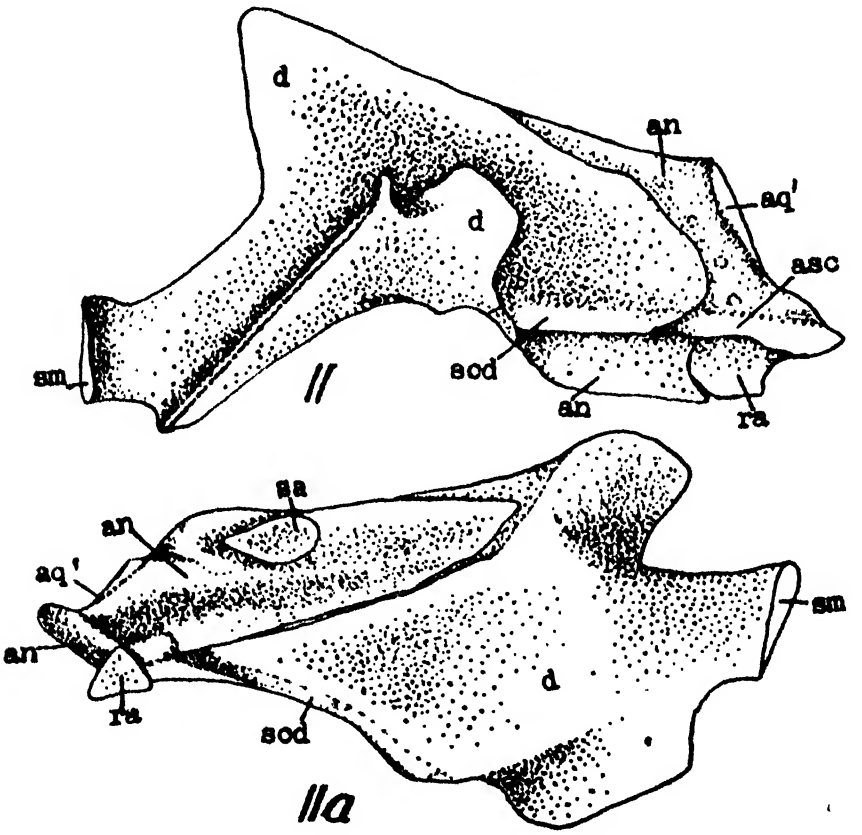


FIG. 11. Lateral aspect of the right ramus of the lower jaw of *Garra mullya* Sykes.
FIG. 11a. Mesial aspect of the same.

The Weberian apparatus : The Weberian apparatus is closely associated with the first four vertebrae and that in the Ostariophysi has been exhaustively described by previous workers (Sagemehl, 1885; Hora, 1922; Evans, 1925; Chranilov, 1927; Watson, 1939; Krumholz, 1943; Nelson, 1948). For purposes of comparison, I have drawn a figure of the Weberian apparatus and the first five vertebrae of *Garra* (fig. 14). In *Garra* the short first centrum (c_1) with its elongated dorsal rib is devoid of its dorsal part. This dorsal part has, however, been noticed in *Labeo* (Sarbahi, 1932) where it is described as the keystone part. What exactly

is the origin of this Λ-shaped piece, it is difficult to say now. It is very likely that just as 'a large mass of cartilage which, in the adult stage, when the centra of the second and third vertebrae have fused, becomes ossified to form the neural spine and arches of the "compound" vertebra' (Watson, 1939), this also represents an ossification in the region of the second vertebra and not first, and we are therefore justified in calling it the second neural arch and spine (fig. 14, na_1) as has been done by me. However, Matveiev (1929) and Watson (1939) referred to a peculiar ring of cartilage surrounding the spinal cord in the region of the first vertebra and the latter author opined that it might be the extension of the exoccipitals and in the adult it formed a bony covering for the cavum sinus imparis. The centra of the second and third vertebrae are fused in *Garra* as in *Labeo* (Sarbahi, 1932); however, in the Cyprinidae Regan (1911) recorded that the first two vertebrae were free. Anteriorly from the centrum of the second vertebra there arises a large dorsal rib in *Garra* (fig. 14, pr_2). As described by Watson (1939) in the goldfish, the neural arch in the region of the third vertebra in *Garra* may also be an ossification in a large mass of cartilage in this region. The fourth vertebra is typical and shows an elongated dorsal rib (fig. 14, pr_4) and a large neural spine (ns_4).

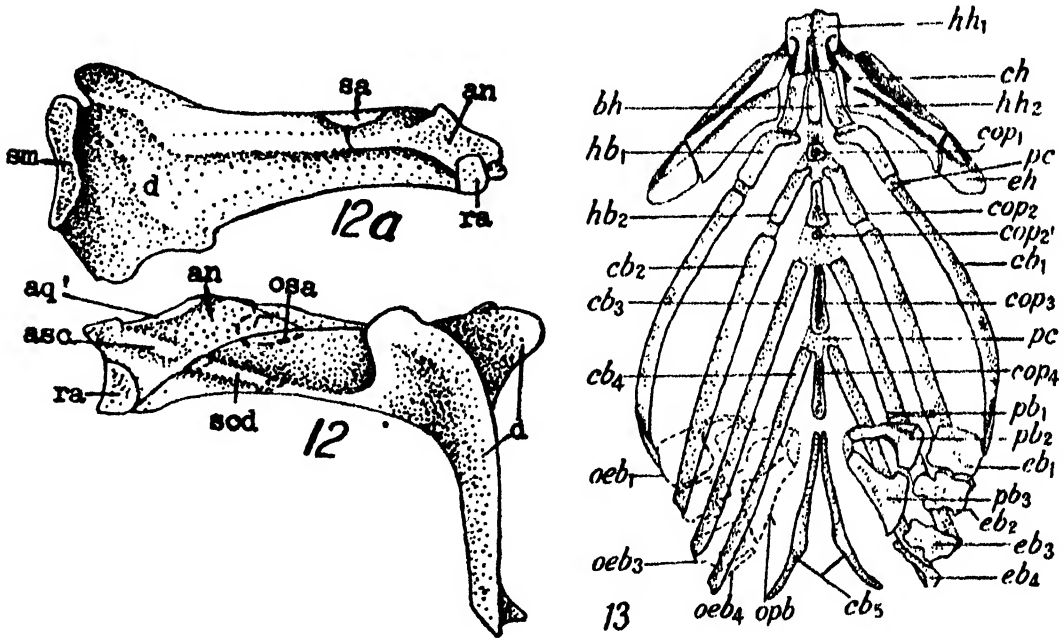


Fig. 12. Lateral aspect of the right ramus of the lower jaw of *Crossocheilus latius* (Ham.).
Fig. 12*a*. Mesial aspect of the same.
Fig. 13. Hyobranchial apparatus of *Gyrinocheilus kaznakoi* Berg.

Associated with the second neural arch described above, there is the claustrum (fig. 14, *cl*) in *Garra* and it fits into the cupshaped second bone,—the scaphium (*sc*) of the apparatus. From the scaphium there arises the thick interosseous ligament (*li*) in which the outer end of the intercalarium (*ic*) is noticed with its inner end (the basidorsal portion) coming in contact with the neurocentral suture of the second vertebra resembling exactly the figure of the cyprinid type of the Weberian apparatus drawn by Chranilov (1927). From the outer end of the ligament in *Garra*, there is the large triradiate tripus (*tr*); a mesial limb of this comes in contact with the posterior part of the united centrum of the second and third vertebrae. The bent spinelike posterior end of the tripus is attached to the anterior wall of the gasbladder.

Watson (1939) derived the Weberian ossicles in the goldfish somewhat differently from the previous authors. According to him, the claustrum arose as a membrane

bone in the mesenchymatous mass in the inner wall of the atrium sinus imparis. The s aphium was of dual origin; the basidorsal of the first vertebra united with a few mesenchymatous cells to give rise to this second ossicle. The intercalarium also arose in part (the articular process) from the basidorsal of the second vertebra and partly as a sesamoid bone (manubrium incudis). The anterior and articulating processes of the tripus were basiventral derivatives of the third vertebra; the main body of it was derived from a mesenchymatous mass and the rib rudiment gave rise to the transformator processes which latter came in contact with the gasbladder.

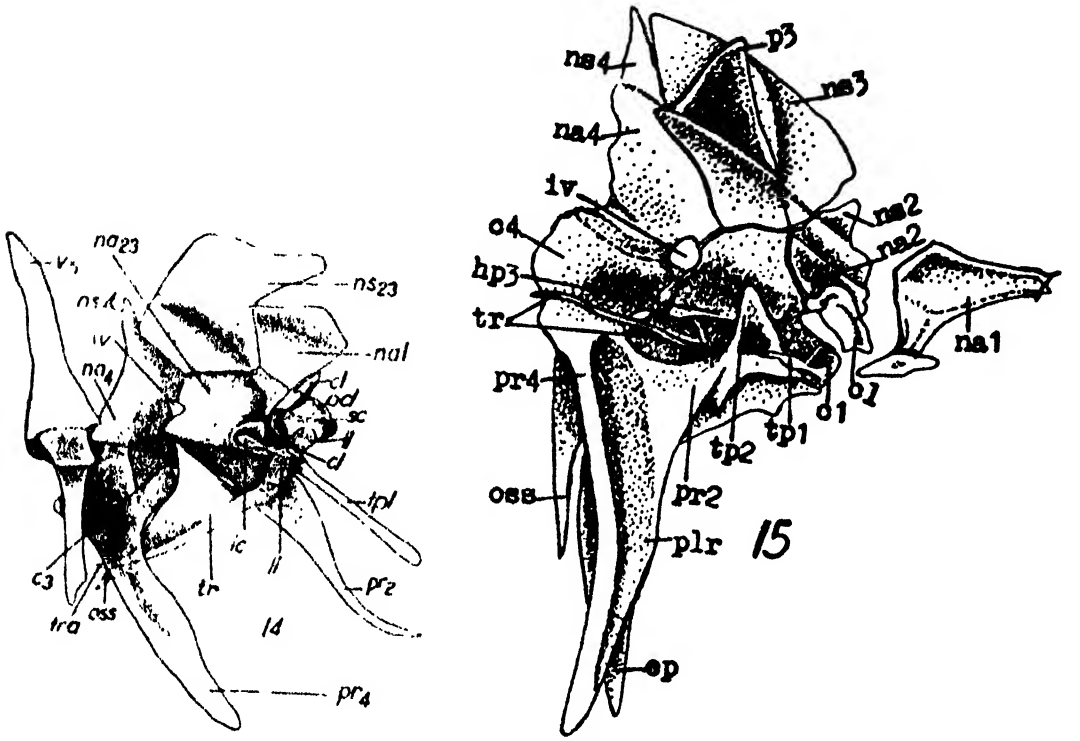


FIG. 14. Right lateral view of the first five vertebrae and Weberian ossicles of *Garra mullya* Sykes.

FIG. 15. Right lateral view of the first four vertebrae of *Gyrinocheilus kaznakoi* Berg.

With this as the background if we examine the Weberian apparatus of *Gyrinocheilus*, certain important differences are noticed. The first thing that one notices is the semicircular arch (fig. 15, na_1) in front of the first vertebra. As already said, this may represent an ossification of an independent piece of cartilage in front of the first pair of basidorsals. Just as Watson (1939) has labelled similar ossification in the second-third vertebral region as neural arch and spine, I have also called this the first neural arch in *Gyrinocheilus* (fig. 15, na_1). The first vertebra is represented by the centrum (c_1), a pair of dorsal ribs (tp_1) or transverse processes according to older nomenclature, and the scaphium (not shown in the figure) which, following Watson (1939), is probably derived from the basidorsal of this segment. The centra of the second and third vertebrae are fused and anteriorly, the centrum of the second vertebra shows a laterally directed short dorsal rib (tp_2) and a pleural rib (pr_2) which has united with a similar pleural rib (pr_4) of the fourth vertebra simulating the condition met with in the Catostomidae (Nelson, 1948). The third vertebra is devoid of dorsal or pleural ribs; the neural arches and spines of the second and third vertebrae (fig. 15, na_2, ns_2, ns_3) are *not* fused but are independent as in the Catostomidae. The neural arch and spine of the third vertebra in *Gyrinocheilus* is also expanded as in the Catostomidae (Nelson, 1948) and is probably

formed by the addition of the interspinous elements and represents, like the catostomid one, a neural complex. Further, the neural complex also bears on either side a prominent process (p_3) in *Gyrinocheilus*, which however, is not seen in Catostomidae. In the Cyprinidae, the neural arches of the second and third vertebrae arising independently of their basidorsals unite to form a composite structure (Sarbahi, 1932; Watson, 1939). There is a lateral shelflike projection (hp_3) from the pedicel of the third vertebra in *Gyrinocheilus* mesially to the dorsal rib (rp_2) of the second vertebra extending anteriorly over the united second and third centra. A similar shelf is also described in the Catostomidae by Chranilov (1926) and Nelson (1948). The pleural rib* (pr_2) arising from the centrum of the second vertebra in *Gyrinocheilus* and uniting with that of the fourth vertebra (pr_4) leaves a large paravertebral gap below the shelf referred to above between the third and fourth vertebrae. The neural arch (na_4) and neural spine (ns_4) of the fourth vertebra are slightly enlarged and there is a large intervertebral foramen (iv) between the third and fourth neural arches. The pleural ribs of the fourth vertebra are not united mesially to form a 'transverse plate' as in the Catostomidae (Chranilov, 1926; Nelson, 1948) but each shows from its incomplete transverse projection an elongated posterior process,—the os suspensorium (*oss*) representing the haemapophyses of the segment and also an esophageal process (*ep*) supporting the esophagus as in the Catostomidae. This arrangement of parts in the first four vertebrae of *Gyrinocheilus* suggests a possible evolution towards the catostomid type.

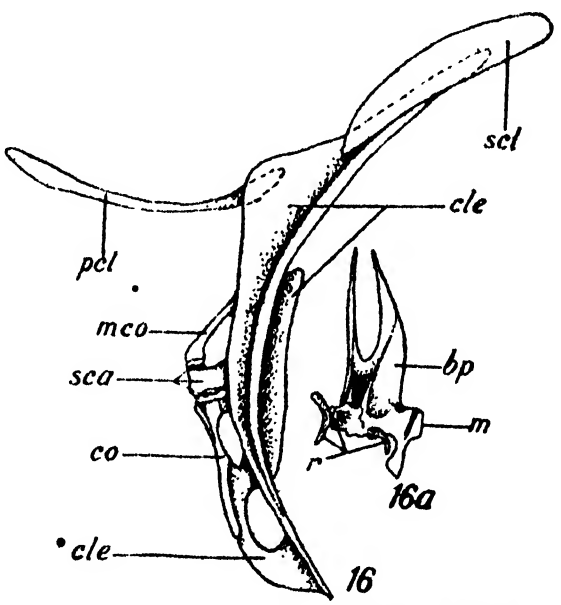


FIG. 16. Pectoral girdle of the right side of *Gyrinocheilus kaznakoi* Berg.
FIG. 16a. Pelvic girdle of the right side of *G. kaznakoi* Berg.

Fitting into the inner face of the claustrum in *Gyrinocheilus* (fig. 15, *cl*) is the scaphium (not drawn in the figure) from the ventral face of which is a ligament in which a nodulelike intercalarium is seen. The ligament passes below the shelflike extension of the third neural arch and meets the tripus (*tr*). The tripus which is lodged in the paravertebral gap between the third and fourth vertebrae, articulates with the third centrum by a facet and posteriorly has a process which comes in contact with the gasbladder.

* Following the nomenclature of Nelson (1948).

The arrangement of the first four vertebrae and the disposition of the ossicles in *Gyrinocheilus* resembles more the condition met with in the Catostomidae and, therefore, differs from the Cyprinid type.

The girdles: The pectoral girdle of *Gyrinocheilus* (fig. 16) differs from that of the Cyprinid only in shape while all the bones of the girdle, viz., the supracleithrum (*scl*), the cleithrum (*cle*), the coracoid (*co*), the mesocoracoid (*mco*), the postcleithrum (*pcl*) and the scapula (*sca*) are noticed. The pelvic girdle (fig. 16*a*) possessing a large pair of pelvic bones (*bp*) resembles that of the cyprinid in shape also.

Discussion.

There are a few features in which the skull of *Gyrinocheilus* resembles that of *Garra* and *Crossocheilus* or the Cyprinidae in general but there are a number of important features in which it differs.

The possession of a broad supraethmoid part of the ethmoid bone which firmly articulates with the frontals and the anterolaterally situated nodule of bone,—the pre-ethmoid articulating with the anterior extension of the prevomer and the ethmoid are characteristic of Cyprinidae. In *Gyrinocheilus* also, the firmly united supra-ethmoid portion of the ethmoid and the pre-ethmoid are noticed.

The premaxillae and maxillae of *Gyrinocheilus* though showing the characteristic processes noticed in the Cyprinidae, differ in size and disposition. The rostral process of the premaxilla, however, is very short and does not lie dorsally to the rostral and the lateral process of the premaxilla is also very short; it does not run in companionship with that of the maxilla as in the cyprinids. From the posterior face of the maxilla there is a large prominent prevomerine process in *Gyrinocheilus* while in the Cyprinidae, there are two; one for the articulation with the palatine and the other with the prevomer.

The median rostral itself differs in shape from what is seen in the Cyprinidae The bone is almost anchorshaped and as recorded above, it is not overlain by the premaxillary process. The posteromedian limb is noticed between the anterior projections of the prevomer.

The prevomer of *Gyrinocheilus* in its anterior extensions and in its articulation with the pre-ethmoid resembles the Cyprinidae; but the shape of the entire bone is very different from what is seen in the Cyprinidae. The long or short posteromesial process so commonly met with among the Cyprinidae is not so prominently noticed in *Gyrinocheilus*; the anterior processes of the prevomer are long and invariably in the Cyprinidae, the ethmoid extends as a median projection dorsally to the prevomer and this projection is absent in *Gyrinocheilus*, where however, the posterior process of the rostral is accommodated in between the two projections of the prevomer.

The lateral ethmoid of *Gyrinocheilus* differs from that seen in the Cyprinidae in two important respects; while the lacrimal process (or lacrimojugal process) of the lateral ethmoid in *Gyrinocheilus* is long unlike in *Garra* and *Crossocheilus*, the posterior process is considerably reduced. Further, on the ventral aspect, the lateral ethmoids extend far posteriorly so as to underlie the optic foramen, a feature not met with in any cyprinid studied.

In a number of cyprinids the ventral portions of the orbitosphenoids come together and project to meet a dorsal process coming up from the parasphenoid to form an interorbital septum; in others this septum may be absent. In *Gyrinocheilus* an interorbital septum is wanting.

The sensory canal bones conform to the cyprinid type. The lacrimal in *Gyrinocheilus* is a fairly long bone coming in contact with the lateral aspect of the palatine. It is not possible to say if this bone represents an united lacrimojugal or lacrimorostral. There are six canal bones in the suborbital series including the lacrimal.

In the pterotic region the canal bones are not independent but are incorporated in the roof of the pterotic; there is one corresponding to the intertemporal or temporal

and a posterior triradiate one corresponding to the supratemporal, the latter establishing connexion with the occipital canal mesially and the lateral line posteriorly. In the cyprinids also, the intertemporal or temporal and the supratemporal are not seen as independent bones but the canal passes through the dorsal aspect of the pterotic.

There is a very peculiar feature in the pterotic region of *Gyrinocheilus*. There is a lateral temporal fossa which is bounded mesially by the epiotic and the pterotic and posteriorly and anteriorly by the epiotic and pterotic respectively. Dorsally the parietal roofs it. In his description of the Cyprinidae, Regan (1911) did not refer to this interesting feature in *Gyrinocheilus*, a species of which he examined. The fossa in *Gyrinocheilus* does not correspond with the one described by Regan either in the Catostomidae or Cyprinidae. In the former family, he stated that paired fossae were present in the temporal region 'open above and closed behind but no posterior temporal fossae'. Similarly in the Cyprinidae he recorded that there were no temporal depressions, 'but supratemporal fossae more or less distinct, open behind, roofed by the posttemporal and sometimes by the pterotic and parietal' were present. Obviously, *Gyrinocheilus* in possessing a lateral temporal fossa which in being closed above differs from the Catostomidae and in being closed behind differs from the Cyprinidae.

The auditory region of *Gyrinocheilus* also shows a subtemporal fossa accommodated in the pterotic, prootic and exoccipital bones like the cyprinids and catostomids and this fossa gently projects into the lateral temporal fossa.

In the Cyprinidae the two exoccipitals bound the foramen magnum dorsally. They also extend mesially over the basioccipital to form a chamber for the accommodation of the sinus impar of the endolymphatic sacs; a lateral fenestra is also seen in each exoccipital. In *Gyrinocheilus*, the exoccipitals do not bound the foramen magnum nor do they disclose fontanels. However, there is a large notch between the supraoccipital and each exoccipital suggestive of a reminiscent fontanel.

The basioccipital in *Gyrinocheilus* shows two projections posteriorly which however, do not unite below the aorta and therefore, the condition resembles that in the Homalopteridae (Regan, 1911). It has already been recorded by Regan that a horny pad covering the bony extension of the basioccipital, a distinguishing feature of the Cyprinidae is absent in *Gyrinocheilus*.

In possessing the typical bones of the upper and lower jaws, *Gyrinocheilus* resembles closely the Cyprinidae; but there are at least three important differences noticed in the upper jaw of that species. In *Garra* and *Crossocheilus*, the opercular shows a prominent process towards the pterotic facet of the hyomandibula and also a sensory canal which connects the temporal (or intertemporal) with the preopercular. The opercular of *Gyrinocheilus* does not show these features. Further, the posterior process of the quadrate is disposed laterally to the preopercular in *Garra* and *Crossocheilus* while in *Gyrinocheilus* the process is mesial.

There are three important features in which the hyobranchial apparatus of *Gyrinocheilus* differs from that in the Cyprinidae. There are three pairs of pharyngobranchs and two pairs of hypobranchs in *Gyrinocheilus* whereas in the cyprinids, there are two pairs of pharyngobranchs and three pairs of hypobranchs. The fifth pair of ceratobranchs is slender in *Gyrinocheilus* and is devoid of teeth (Regan, 1911) unlike what is seen in the Cyprinidae. The occurrence of double row of gill-rakers on the dorsal aspect of the branchial arches of *Gyrinocheilus* has already been recorded by Regan. Peculiarly the rakers extend on the median copulae also. In the Cyprinidae, the branchial arches and the copulae are free of rakers.

The first four vertebrae are modified in *Gyrinocheilus* and resemble those in Catostomidae more than those in the Cyprinidae. The fusion of the pleural ribs* of the second and fourth vertebrae by the side of the third centrum leaving a large

* Following the nomenclature of Nelson (1948).

paravertebral space, the absence of dorsal or pleural ribs from the third vertebra and the possession of a horizontal shelf extending over the paravertebral space referred to above and the partial covering of the tripus by the shelf and the occurrence of independent second and third neural arches and spines in *Gyrinocheilus* are all features common to the Catostomidae. But in *Gyrinocheilus* the formation of the 'transverse plate' from the mesial aspect of the fourth pair of pleural ribs is not so complete as in the Catostomidae. In the Cyprinidae, the centra of the second and third vertebrae are fused; there is no extension from the pedicel of the third vertebra in the form of a shelf to cover the large tripus. Further, the transverse processes are really the dorsal ribs (Watson, 1939), a point which I am not able to substantiate in *Gyrinocheilus* as I have not studied its development. Similarly I am not commenting upon the origin of the Weberian ossicles in *Gyrinocheilus*.

Conclusion: In order to assess the systematic position of *Gyrinocheilus*, it is necessary to find out in what characters the skull of the same resembles that in the cyprinoids. In the nature and disposition of the ethmoid, in the general arrangement of the bones of the upper and lower jaws, in the disposition of the sensory canal bones in the orbitotemporal and auditory regions, in the possession of a pre-ethmoid bone and of a subtemporal fossa *Gyrinocheilus* resembles closely the Cyprinidae.

These similarities could not be without significance. Undoubtedly *Gyrinocheilus* must have taken its origin from a cyprinoid ancestor and probably moved parallelly with the Cyprinidae and Catostomidae since the Weberian apparatus in the Siamese species is more catostomid in construction than cyprinid, but it deviated from the parental stock much, and it now exhibits the following differences from the Cyprinidae:

1. The shape of the median rostral is unlike what is generally seen in the Cyprinidae.
2. The premaxilla does not show an elongated rostral process nor a large lateral limb.
3. The palatine while showing an articular facet for the lacrimal (lacrimojugal or lacrimorostral) possesses a long posterior process for the articulation of the entopterygoid.
4. The prevomer shows two elongated anterior processes and posteriorly, it is widened; a posteromedial process is barely indicated.
5. The lateral ethmoid shows laterally a prominent lacrimal (lacrimojugal or lacrimorostral) process while the posterolateral process is reduced; the ventromesial portion extends into the optic foramen.
6. The prootic region exhibits a lateral temporal fossa.
7. The exoccipitals do not bound the foramen magnum nor do they exhibit the lateral fenestra; the basioccipital does not show a large pharyngeal process uniting below the dorsal aorta.
8. The hyobranchial apparatus shows two hypobranchs and three pharyngobranchs and the gillrakers extend on the dorsal aspect of the copulae also.
9. In the upper jaw, the opercular does not show a process towards the hyomandibula as in *Garra* and *Crossocheilus*, nor a sensory canal in it; the posterior process of the quadrate is not lateral but mesial in disposition.
10. The Weberian apparatus resembles more the catostomid type.

A comparison of the figures of the dorsal and ventral aspects of *Garra*, *Crossocheilus* and *Gyrinocheilus* reveals at once the differences between the cyprinid genera and the latter; in the shape and disposition of the premaxilla, of the prevomer, of the lateral ethmoid, of the ethmoid, of the nasal, and of the great elongation of the ethmoid region of *Gyrinocheilus* and in the absence of a fontanel bounded by the exoccipital and in the possession of a lateral temporal fossa, *Gyrinocheilus* differs

from *Garra* and *Crossocheilus* in particular and in order to find out the probable progenitor from which *Gyrinocheilus* could have taken its origin, I have searched in vain. The characters appear to be so aberrant that it has not been possible to derive *Gyrinocheilus* from any native cyprinid genus that I have studied. I have not examined any exotic forms and in its modification of the first four vertebrae and in the disposition of the Weberian apparatus, *Gyrinocheilus* resembles more the catostomid of which no representative is found in India and therefore, I could only venture to say, at present, that the probable ancestor of *Gyrinocheilus* may not be an Indian cyprinid.

In view of the overwhelming differences between the cyprinid and *Gyrinocheilus* skulls, there is ample justification for the erection of the family Gyrinocheilidae to accommodate the single genus *Gyrinocheilus* as has been done by Hora (1923).

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Key to lettering.

amr., anterior process of median rostral; *amy.*, anterior myodome; *an.*, angular; *apv.*, anterior projections of the prevomer; *aq.*, articular facet for lower jaw; *aq'.*, articular facet for quadrate; *asc.*, sensory canal in the angular; *atf.*, anterior opening of the trigeminofacialis chamber; *bh.*, basihyal; *bo.*, basioccipital; *bp.*, pelvic bone; c_1, c_2, c_3, c_4, centrum of the first, second, third and fourth vertebrae; cb_1, cb_2, cb_3, cb_4, cb_5, ceratobranchials 1, 2, 3, 4, 5; *ch.*, ceratohyal; *cl.*, claustrum; *cle.*, cleithrum; *co.*, coracoid; cop_1, cop_2, cop_3, cop_4, copulae 1, 2, 3, 4; cop_2', a median ossification posterior to copula 2; *d.*, dentary; *dlp.*, dorsolateral process of median rostral; *dmp.*, dorsomedian process of median rostral; *dpp.*, dorsal premaxillary process of maxilla; eb_1, eb_2, eb_3, eb_4, epibranchials 1, 2, 3, 4; *ecp.*, ectopterygoid, *enp.*, entopterygoid; *eoc.*, exoccipital; *eor.*, exoccipital roof of the sinus impar; *ep.*, esophageal process; *epi.*, epiotic; *epl.*, epiotic articulation of post-temporal; *et.*, ethmoid; *fhy.*, articular facet in pterotic and sphenotic; *fma.*, articular facet in the maxilla; *fr.*, frontal; hbr_1, hbr_2, hypobranchial 1, 2; hh_1, hh_2, hypohyal 1, 2; *hp.*, bony plate for attachment of horny pad; hp_3, horizontal projection from third vertebra; *hy.*, hyomandibula; *ic.*, intercalarium; *iop.*, interopercular; *itc.*, intertemporal region; *iv.*, intervertebral foramen; *jf.*, jugular foramen; *l.*, lacrimorostral; *lc.*, lacrimorostral projection of lateral ethmoid; *les.*, lateral extrascapular; *let.*, latera lethmoid; *lf*, the reminiscent lateral fenestra between the supraoccipital and exoccipital; *li.*, ligament; *llm.*, lateral process of maxilla; *llp.*, lateral limb of premaxilla; *lpm.*, lateral projection of premaxilla; *ltf.*, lateral temporal fossa; *m.*, median articular facet of pelvic bone; *ma.*, median preethmoid articular facet of palatine; *max.*, maxilla; *mco.*, mesocoracoid; *mp.*, metapterygoid; *mr.*, median rostral; *n.*, nasal; *n'.*, sensory canal in nasal; na_1, neural arch of vertebra 1 in fig. 15 and vertebra 2 in fig. 14; na_2, neural arch of vertebra 2 in fig. 15; na_4, neural arch of vertebra 4; $na_{3?}$, neural arch of vertebra 3; ns_4, neural spine of vertebra 4; $ns_{2?}$, neural spine of vertebra 3; *ocl.*, outline of claustrum; oeb_1, oeb_3, oeb_4, outline of epibranchials 1, 3, 4; *of.*, optic foramen; *oio.*, outline of interopercular; *oma.*, outline of maxilla; *op.*, opercular; *opa.*, outline of palatine; *opb.*, outline of pharyngobranchs 3, 4; *ope.*, outline of pre-ethmoid; *opr.*, opercular process towards hyomandibula; *oqp.*, outline of quadrate process; *os.*, orbitosphenoid; *osa.*, outline of sesamoid angular; *oss.*, projection of os suspensoria; *pa.*, parietal; *pah.*, pterotic articular facet of hyomandibula; *pal.*, palatine; *pam.*, palatine process of maxilla; *pas.*, parasphenoid; pb_1, pb_2, pharyngobranchs 1, 2; pb_3, united pharyngobranchs 3, 4; *pc.*, cartilaginous remnants between the bones of the hyobranchial apparatus; *pcl.*, postcleithrum; *pet.*, preethmoid; *php.*, pharyngeal process; *plr.*, pleural rib; *pls.*, pleurosphenoid; *pmr.*, posteromedian process of median rostral; *pmx.*, premaxilla; *pmy.*, posterior myodome; *pop.*, preopercular; *ppr.*, pterotic process; *ppt.*, pterotic limb of post-temporal; *pr.*, winglike process of the median rostral; *pro.*, prootic; pr_2, pr_4, dorsal ribs of vertebrae 2, 4 in fig. 14 and pleural rib in fig. 15; *pt.*, post-temporal; *pte.*, pterotic; *pv.*, prevomer; *pvm.*, prevomerine process of maxilla; p_3, projection from the neural complex of third vertebra; *q.*, quadrate; *qp.*, posterior process of quadrate; *r.*, radials; *ra.*, retroarticular; *rpm.*, rostral process of maxilla; *sa.*, sesamoid angular; *sah.*, sphenotic articular facet of hyomandibula; *sc.*, scaphium; *sca.*, scapula; *scd.*, sensory canal in dentary; *scl.*, supracleithrum; *sco.*, sensory canal in opercular; *se.*, supraethmoid portion of ethmoid; *seo.*, opening of the sinus impar in the exoccipital; *sm.*, symphysis meckelii; *so.*, supraoccipital; *so.*, orbitosphenoid in figs. 4, 6; so_2, so_3, so_4, so_5, so_6, suborbitals 2, 3, 4, 5, 6; *soc.*, supraorbital sensory canal; *sop.*, subopercula; *sp.*, sphenotic; *spo.*, sensory canal in preopercular; *spr.*, sphenotic process; *ste.*, supratemporal region; *stf.*, subtemporal fossa; *suo.*, supraorbital; *sy.*, symplectic; *tf.*, trigeminofacialis chamber; tp_1, tp_2, dorsal ribs of vertebra 1, 2; *tr.*, tripus; *tra.*, posterior portion of tripus; v_5, fifth vertebra.

* This paper was not accessible to the author.

SKELETON OF CYPRINOID FISHES IN RELATION TO PHYLOGENETIC STUDIES.

II. The Systematic position of *Psilorhynchus* McClelland.

By L. S. Ramaswami, *Senior Research Fellow, N.I.S.I., Department of Zoology, Central College, Bangalore*

(Communicated by Dr. S. L. Hora, D.Sc., F.N.I.)

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Introduction.

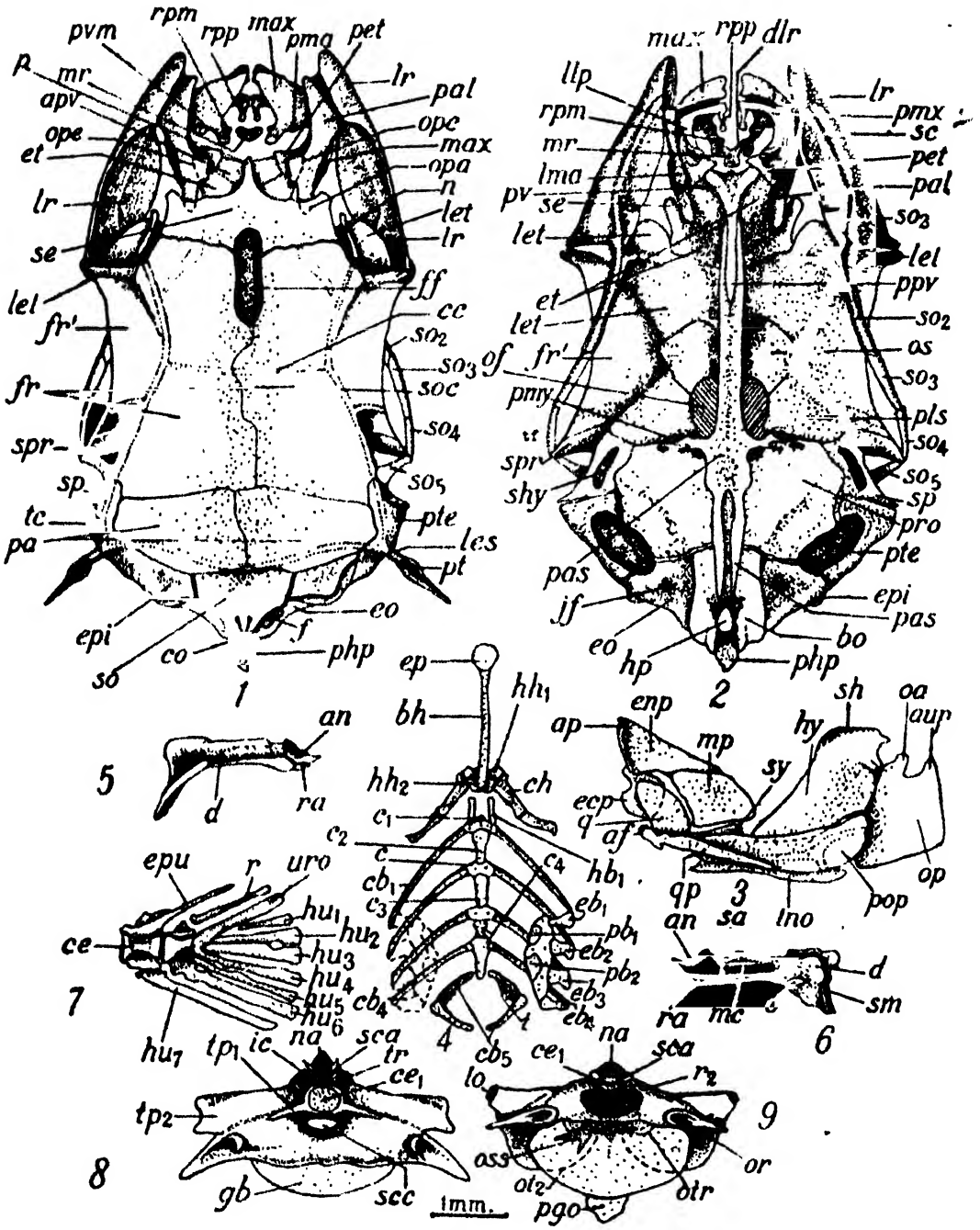
Hora (1925) established the family Psilorhynchidae to accommodate the Assamese hillstream fish *Psilorhynchus* McClelland after a careful examination of the external characters and also of the pharyngeal bones. He pointed out that each pharyngeal bone carried four teeth which were arranged in a single row. This feature associated with the presence of a number of simple rays in the paired fins precluded the inclusion of *Psilorhynchus* in the Cyprinidae. Similarly he pointed out that the absence of barbels and the presence of a free gasbladder in the abdominal cavity separated it from the Homalopteridae and Gastromyzonidae; and from the Cobitidae, it is distinguished, 'by the presence of large scales, by the presence of several simple rays in the horizontally placed paired fins, by the absence of barbels and in its general facies' (Hora, 1925).

In describing the family characters, Hora (1925) again referred to the nature of the arrangement of the teeth on the pharyngeal bones and with regard to the gasbladder, he pointed out that it was normal but reduced and according to him, 'it is either entirely free in the abdominal cavity or is partially covered by bone. The posterior chamber is very small and the anterior is covered by thick fibrous coat.' Obviously there is difference in the nature of the disposition of the gasbladder in these species. A progressive degeneration of the bladder is noticed in both species of *Psilorhynchus*, viz., *balitora* and *sucatio*.

It was suggested to me by Dr. Hora during our discussions on phylogenetic studies, that I should also examine the small hillstream cyprinine fish *Parapsilorhynchus* Hora which closely resembles *Psilorhynchus*. Accordingly specimens of *Parapsilorhynchus* were made available to me from the collections of the Indian Museum, Calcutta. *Parapsilorhynchus* differs from *Psilorhynchus* in three important external characters, viz., the possession of two cylindrical barbels, of the concealed upper lip and of the commencement of the dorsal opposite the ventrals (Hora, 1921). The gasbladder in *Parapsilorhynchus* is typically cyprinine in having an anterior and a posterior portion.

Observations.

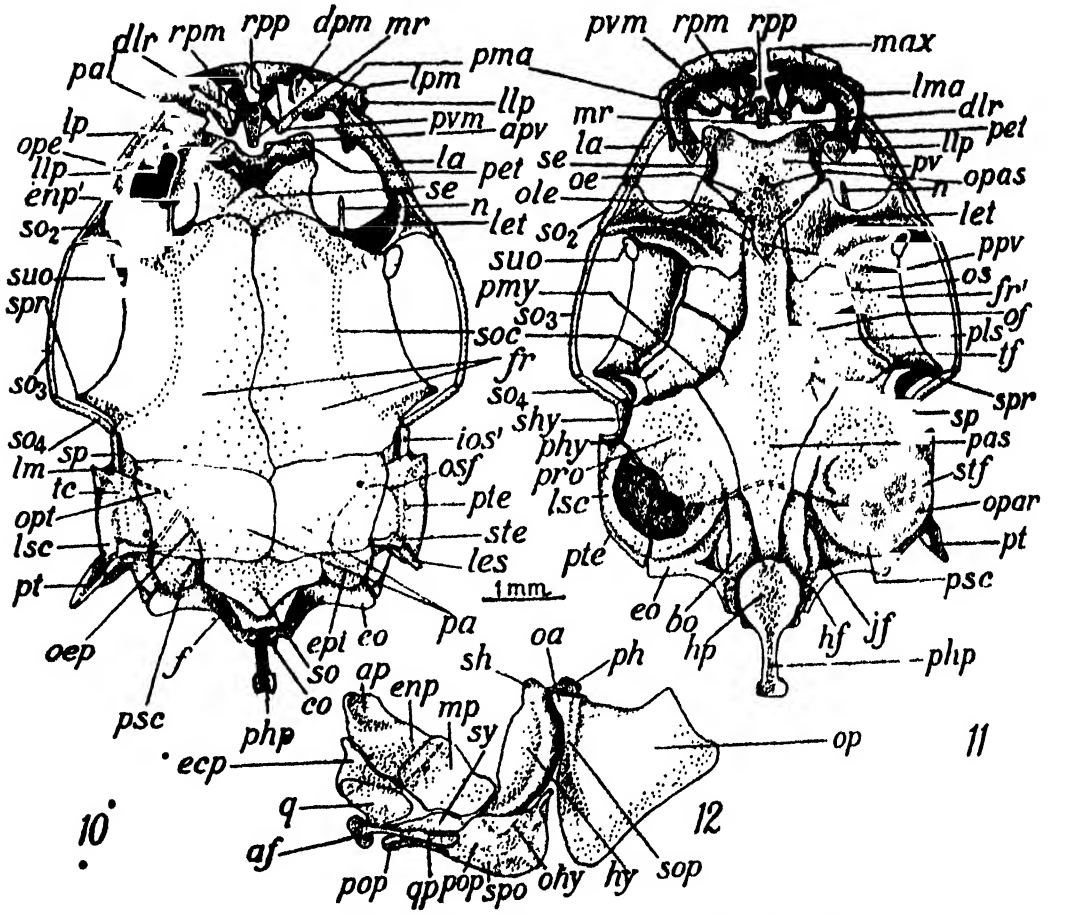
I have examined *Psilorhynchus sucatio* (Ham.) and *Parapsilorhynchus tentaculatus* (Annandale). There is a general flattening of the skull in both *Psilorhynchus* and *Parapsilorhynchus* which is obviously an adaptation for hillstream life and the former is also known to burrow in sand; in the specimen of *Psilorhynchus* examined by me, the skull appears to be comparatively longer than in *Parapsilorhynchus*.



TEXT-FIG. 1. Dorsal aspect of the skull of *Psilorhynchus sucatio* (Ham.).
TEXT-FIG. 2. Ventral aspect of the skull of *P. sucatio*; the palatines, the nasals and the post-temporals are not drawn.
TEXT-FIG. 3. The upper jaw of *P. sucatio*; the palatine is not drawn.
TEXT-FIG. 4. The hyobranchial apparatus of *P. sucatio*.
TEXT-FIG. 5. Lateral view of the left ramus of the lower jaw of *P. sucatio*.
TEXT-FIG. 6. Mesial view of the left ramus of the lower jaw of *P. sucatio*.
TEXT-FIG. 7. The caudal fin skeleton of *P. sucatio*; the fin rays are not drawn.
TEXT-FIG. 8. Anterior view of the Weberian ossicles and gasbladder of *P. sucatio*.
TEXT-FIG. 9. Ventral view of the Weberian ossicles and gasbladder of *P. sucatio*; the os suspensorium is drawn on one side.

The ethmoid region: The premaxilla in *Psilorhynchus* and *Parapsilorhynchus* show the characteristic cyprinid rostral process (figs. 1, 2, 10, 11, *rpp*) which however, does not sit on the median rostral (*mr*) but is away from it. The lateral limb (figs. 2, 10, 11, *llp*) is bent almost at right angles to the horizontal one carrying the rostral process and shows an expanded posterior part. The maxilla of *Psilorhynchus* shows two peculiarities: the dorsal premaxillary process so prominently noticed in the cyprinid maxilla (fig. 10, *dpm*) is absent in it. Further, the prevomerine process (figs. 1, 2, *pvm*) of the maxilla in *Psilorhynchus* shows a very short rostral process (*rpm*) which unlike that in the cyprinids (figs. 10, 11, *rpm*) does not form a fork with the dorsal part of the maxilla (figs. 1, 2, *max*) to hold the premaxilla in it. The maxilla also shows a small projection (fig. 1, *pma*) towards the palatine and an elongated one (*pvm*) towards the prevomer in *Psilorhynchus*.

The median rostral (figs. 1, 2, 10, 11, *mr*) in both *Psilorhynchus* and *Parapsilorhynchus* is a short rodlike structure with two dorsolateral projections (*dlr*) for the attachment of ligaments from the rostral processes of the maxilla.



TEXT-FIG. 10. Dorsal aspect of the skull of *Parapsilorhynchus tentaculatus* (Annandale); the palatine and the post-temporal are drawn on one side.

TEXT-FIG. 11. Ventral aspect of the skull of *P. tentaculatus*; the palatines are not drawn and the post-temporal is shown on one side.

TEXT-FIG. 12. The upper jaw of *P. tentaculatus*; the palatine is not drawn.

The supraethmoid part of the ethmoid (fig. 1, *se*) is very broad in *Psilorhynchus* and extends in the form of a projection (*p*) in the middle. In *Parapsilorhynchus* (figs. 10, 11, *se*) it is not so broad and is seen as two lateral winglike extensions dorsally

to the prominent prevomerine projection (*apv*). In front of the ethmoid in *Psilorhynchus* (fig. 1, *et*) dorsally, the prevomerine projection (*apv*) is seen and on either side of these two, i.e., the ethmoid and the prevomerine projection, as in the Cyprinidae (figs. 10, 11 *pet*), the pre-ethmoid (figs. 1, 2, *pet*) is noticed. There is a large median indentation in the posterior border of the supraethmoid (*se*) in *Psilorhynchus* caused by a fossa (fig. 1, *ff*) noticed between the supraethmoid and the frontals (*fr*); in *Parapsilorhynchus* this is absent.

In *Psilorhynchus*, the lateral ethmoid (fig. 1, *let*) is seen in the dorsal aspect only partially since the lateral extension of the frontal (*fr'*) covers the posterodorsal part of it. Ventrally the lateral ethmoid (fig. 2, *let*) forms the floor of the anterior orbitotemporal region. In *Parapsilorhynchus*, a large part of the lateral ethmoid (fig. 10, *let*) is seen dorsally as in the other cyprinids but ventrally, it (fig. 12, *let*) does not extend as far posteriorly as in *Psilorhynchus*. In both genera, the lateral processes, viz., the lacrimal process and the one on the opposite side are poorly developed, thereby differing from the Homalopteridae and the Gastromyzonidae where these processes are well developed.

The lacrimal (figs. 1, 2, *lr*) is excessively enlarged in *Psilorhynchus*, a feature not noticed in any cyprinid studied by me (figs. 10, 11, *la*) and is very suggestive of the condition met with in the Homalopteridae and Gastromyzonidae. Probably the lacrimal of *Psilorhynchus* represents a united lacrimal and rostral, the latter being a sensory canal ossicle in front of the lacrimal in forms where these can be seen separately; it may not be a fused jugal-lacrimal-rostral since there is a large ossicle posterior to the lacrimorostral probably representing a jugal (fig. 2, so_2). In *Parapsilorhynchus* the lacrimal (figs. 10, 11, *la*) is not enlarged and is as in any other cyprinid; there is no rostral sensory canal ossicle in front of the lacrimal. However, there is a thin ossicle behind the lacrimal which may be the jugal (so_2). Both in *Psilorhynchus* and *Parapsilorhynchus*, the sensory canals are not separate but are incorporated in the lacrimal (or lacrimorostral, fig. 2, *sc*) and jugal; in the Homalopteridae, the sensory canal is independent of the lacrimorostral.

I prefer to consider the palatine here, though it forms a part of the upper jaw. In *Psilorhynchus*, the palatine (fig. 1, *pal*) is elongated and the anterior third of it is noticed in association with the lacrimorostral; this articulation is suggestive of the facet developed either in the palatine of *Cirrhina* (Cyprininae) to articulate with the lacrimal or as that in the Homalopterid examples. In *Psilorhynchus* the palatine shows a short posterior portion (fig. 1, *opa*) projecting ventrally to the supraethmoid for articulation with the entopterygoid and towards the pre-ethmoid, it also shows an articular facet. In *Parapsilorhynchus*, though the palatine is not so elongated as in *Psilorhynchus*, there is a projection towards the maxilla and the other processes are as in *Psilorhynchus*.

The edentulous prevomer (fig. 1, *apv*) of *Psilorhynchus* extends in front of the ethmoid (*et*) a feature also noticed in the cyprinids (fig. 10, *apv*). The bone is not broad in *Psilorhynchus* (fig. 2, *pv*) but shows a long posterior process (*ppv*); in *Parapsilorhynchus* the bone is very broad (fig. 11, *pv*) and the posterior process (*ppv*) is very short.

The orbitotemporal region: In *Psilorhynchus*, the frontals (fig. 1, *fr*) are wide and laterally they extend over the optic region; between the two frontals and the posterior edge of the supraethmoid (*se*), there is a median fontanel (fig. 1, *ff*) included which appears to be peculiar to *Psilorhynchus*. In no other cyprinid including *Parapsilorhynchus* is such an ethmoid fontanel noticed. In the Cobitidae, between the frontals and parietals there is generally a large or small frontoparietal fontanel; in the Gastromyzonidae, a few genera like *Vanmanenia*, *Crossostoma* and *Glaniopsis* show frontoparietal fontanel. According to Sagemehl (1891) no importance need be attached to the occurrence or otherwise of the latter fontanel in fishes since it appears to be a fortuitous character. The occurrence of fontanels either in the anterior or posterior dorsal region of the skulls of hillstream and sand burrowing

fishes and the Cobitidae which are mud-dwellers may not be, however, without significance.

The orbit is very large in *Psilorhynchus* since it has to accommodate a large eye; this is also a feature noticed in *Parapsilorhynchus*.

Two small supraorbitals (figs. 10, 11, *suo*) are noticed in *Parapsilorhynchus*; in *Psilorhynchus*, the bones are completely wanting.

On either side of the frontals in *Psilorhynchus*, posterior to the lacrimorostral, there are four suborbital sensory canal bones, the first of which is fairly large (fig. 2, so_2) and has been compared to a jugal. In the frontals the supraorbital canals (*soc*) run and the two are connected by a commissure (*cc*). In *Parapsilorhynchus* there are only three suborbital sensory canal ossicles (so_2, so_3, so_4) posterior to the lacrimal and the supraorbital canals which run in the frontals are not connected together by a commissure.

The orbitosphenoid (figs. 2, 11, *os*) and pleurosphenoid (*pls*) bound the optic foramen (*of*) anteriorly and laterally both in *Psilorhynchus* and *Parapsilorhynchus*. It was noticed, however, in *Gyrinocheilus* (Ramaswami, 1952*a*, in press) that the lateral ethmoid extended so far posteriorly as to bound the optic foramen ventrally also. In *Psilorhynchus* and *Parapsilorhynchus* the orbitosphenoids and the underlying parasphenoid do not form an interorbital septum. In the ventral view of the skull of *Psilorhynchus* and *Parapsilorhynchus*, between the pleurosphenoid and the parasphenoid the opening of the posterior myodome (figs. 2, 11, *pmy*) is noticed through which the posterior rectus muscle of the eyeball passes for insertion inside the myodome.

In *Psilorhynchus* the parasphenoid (fig. 2, *pas*) shows a forking in the posterior region as in *Crossocheilus*, one of the Cyprininae studied by me. Such a forking is not seen in the parasphenoid of *Parapsilorhynchus*.

In each eye-ball, there are two cup-shaped sclerotic bones.

The occipito-auditory region: Dorsally this region shows the two parietals (fig. 1, *pa*); the sphenotic (figs. 1, 2, *sp*) discloses a short spinelike process (*spr*) anteriorly and peculiarly, at the region the sphenotic comes in contact with the pterotic posterior to the hyomandibular articulation, the two are separated by a gap. Ventrally the sphenotic shows a single articular facet (fig. 2, *shy*) for the hyomandibular articulation. In *Parapsilorhynchus* the sphenotic shows a sphenotic process (figs. 10, 11, *spr*) and dorsally, there is an independent sensory canal ossicle (fig. 10, *ios'*) sitting on it connecting the supraorbital (*soc*) canal with the temporal canal (*tc*). Ventrally, the sphenotic shows a facet (fig. 11, *shy*) for the hyomandibula which is in close contact with the other facet (*phy*) in the pterotic.

The pterotic (figs. 1, 2, *pte*) in *Psilorhynchus* comes in contact with the postero-lateral edge of the frontal (*fr*) and receives the supraorbital canal which in this region is designated the temporal canal (*tc*). At this region the last suborbital bone (so_5) (sometimes called the postorbital bone also) receives the sensory canal to proceed as the infraorbital canal below the eye. Posteriorly the pterotic also shows the passage into the occipital and laterally into the lateral line canals; at the commencement of the latter, the lateral extrascapular (fig. 1, *les*) is seen sitting on the post-temporal (*pt*). In *Parapsilorhynchus* the independent sensory ossicle (fig. 10, *ios'* sitting on the sphenotic (*sp*) connects the supraorbital (*soc*) canal with the temporal (*tc*). Anteriorly the temporal canal gives off a branch (*lm*) which connects the one in the opercular to go off as the mandibular canal in the preopercular and the lower jaw.

In the cyprinids generally, the post-temporal articulates with the skull by two facets: one coming in contact with the epiotic and the other, when present, with the pterotic. In both *Psilorhynchus* and *Parapsilorhynchus*, the post-temporal (figs. 1, 2, 10, 11, *pt*) has only a single articular facet with the pterotic.

In *Parapsilorhynchus*, there is a deep subtemporal fossa (fig. 11, *stf*) whose outline could be easily made out in the dorsal aspect also (fig. 10, *osf*) through the

transparent parietal (*pa*). In *Psilorhynchus* (fig. 2, *stf*) it is very shallow and resembles more that in some Homalopterid examples.

The exoccipitals in *Psilorhynchus* and *Parapsilorhynchus* exclude the supra-occipital (figs. 1, 10, *so*) from forming the roof of the foramen magnum; also there is a lateral fossa (*f*) in each exoccipital, which is a feature noticed in all Cyprinidae, Catostomidae and Cobitidae.

The basioccipital (fig. 2, *bo*) of *Psilorhynchus* shows a short pharyngeal process (*php*) through which the aorta passes and also a bony projection (*hp*) for the attachment of the horny pad; in *Parapsilorhynchus* also these structures are noticed, only the pharyngeal process (figs. 10, 11, *php*) is very long.

In the structure of the upper (fig. 3) and the lower jaws (figs. 5, 6) *Psilorhynchus* resembles the cyprinids closely. However, there are two peculiarities not commonly seen in the Cyprinidae. The hyomandibular (*hy*) shows a single articular facet (*sh*) for articulation with the sphenotic region. The upper opercular edge shows a deep indentation so that there is a prominent auricular process (*aup*) and the opercular arm (*oa*) seems to be directed not anteriorly but vertically. There is no articular process at the region the preopercular gives articulation to the hyomandibula. The opercular does not carry a sensory canal in it. In *Parapsilorhynchus*, the upper jaw is typically cyprinid; the hyomandibula has two articular facets, one with the sphenotic (fig. 12, *sh*) and the other with the pterotic (*ph*). The opercular shows the prominent opercular arm (*oa*), the auricular process and the sensory canal (*sop*) in it which connects the temporal (fig. 10, *tc*) with the preopercular canal (fig. 12, *spo*).

Peculiarly in *Psilorhynchus* (fig. 6) the lower jaw shows a large orifice (*o*) in the dentary (*d*). This feature is not seen in any other cyprinid including *Parapsilorhynchus* studied by me.

In *Psilorhynchus* the hyobranchial apparatus exhibits only one pair of hypobranchs (fig. 4, hb_1) and this is unique. In the cyprinids, there are always three pairs of hypobranchs including *Parapsilorhynchus* and in *Gyrinocheilus* (Ramaswami, 1952*a*, in press) there are only two pairs. In *Psilorhynchus* there is a considerably elongated basihyal (fig. 4, *bh*) with a roundish cartilaginous epiphysis (*ep*). In *Parapsilorhynchus* there are, as in the Cyprinidae, three pairs of hypobranchs and two pairs of pharyngobranchs. While the fifth ceratobranch in *Psilorhynchus* (fig. 4, cb_5) shows four teeth (*t*) arranged in a row, in *Parapsilorhynchus*, the teeth follow the cyprinid plan.

The Weberian apparatus: In *Psilorhynchus* the gasbladder is divided into a large anterior (fig. 8, *gb*) and a smaller posterior (fig. 9, *pgb*) portions (see Hora and Mukerji, 1935, Pl. VII, fig. 5). The cyprinids also show a division into two. In *Psilorhynchus* the anterior part is partially protected by the enlargement of the dorsal rib (the transverse process of previous authors) of the second vertebra (fig. 8, tp_2) which does not, however, extend on the ventral aspect (fig. 9). Anteriorly a part of this dorsal rib is folded to show a lateral opening (fig. 9, *lo*); this is probably the first step towards the modification of the bony capsule seen in the Nemachilinae (Cobitidae) and the Homalopteridae. The first vertebra shows a round centrum (figs. 8, 9, ce_1) with a pair of dorsal ribs (tp_1). The neural arch of the second vertebra (*na*) which probably arises as an independent cartilage-bone shows in front of it the claustrum (not shown in the figures 8, 9) and scaphium (*sca*) with its prominent processus ascendens stapedis. A slender intercalarium (*ic*) articulates mesially with the second centrum; the tripus, which is cyprinid in shape, is enclosed in the capsule formed by the dorsal rib of the second vertebra and shows a processus anterior, a processus posterior and a processus articularis. The posterior process of the tripus (*otr*) comes in contact with the anterior part of the gasbladder. The tripus in being enclosed resembles the condition in the Nemachilinae and Homalopteridae; but in the latter two, the tripus assumes almost a Y-shape with one of the limbs longer and this limb comes in contact with the centrum

of the third vertebra. In *Psilorhynchus*, on the other hand, the tripus is, however, of the shape noticed in the cyprinids as remarked above. In *Parapsilorhynchus* the Weberian ossicles are not covered over by the capsular wall formed by an extension of the dorsal rib of the second vertebra and therefore, they are typically cyprinid showing the os suspensoria arising from the fourth vertebra. I have already discussed the origin of the Weberian ossicles in my previous paper (Ramaswami, 1952*a*, in press).

With regard to the gasbladder, it has been recorded by Hora (1925) that in *Psilorhynchus* two types are found: one with a free gasbladder and the other enclosed in bone in the same species of the genus. I am obviously examining the second type where the bladder is partially enclosed. I am unable to comment on the other as I have not examined the species with a free gasbladder.

The caudal fin skeleton: In *Psilorhynchus* and *Parapsilorhynchus* the last vertebra shows a prominent urostyle (fig. 7, *uro*) with an unconnected radial in front and with six hypurals (hu_1-hu_6) ventrally to it. The preceding two vertebrae also contribute epurals and hypurals for supporting the fin skeleton. Thus *Psilorhynchus* does not show any variation from the cyprinid type.

Discussion.

Having studied a large number of cyprinid skulls, I am in a position to compare the skulls *Parapsilorhynchus* and *Psilorhynchus* in order to evaluate their mutual relationships.

Parapsilorhynchus is a typical cyprinid, for it exhibits the following characters common to all cyprinids:

1. The premaxilla shows a rostral process.
2. The maxilla also shows a rostral process and the premaxilla is held in a fork of the maxilla. There are two facets posteriorly,—the prevomerine and the palatine, and the latter facet is capped with thick connective tissue to articulate with the palatine.
3. The median rostral exhibits two dorsolateral processes generally for ligamentary connexion with the maxilla.
4. The supraethmoid portion is immovably articulated with the frontals and ventrally, the ethmoid with the projecting prevomerine portion gives articulation to the pre-ethmoid.
5. The lateral ethmoid does not show prominent lateral processes.
6. The pre-ethmoid gives articulation to the palatine.
7. The supratemporal connects the temporal canal with the lateral line and supraoccipital canals.
8. The post-temporal shows two limbs generally, one for articulation with the pterotic and the other with the epiotic.
9. The supraoccipital is excluded from the foramen magnum and the exoccipitals cover it dorsally. Each exoccipital shows a fossa in it; the basioccipital shows a prominent pharyngeal process which allows the dorsal aorta to pass through it, and a bony projection in front of the pharyngeal process for the attachment of a horny pad.
10. The orbitosphenoids and the pleurosphenoids along with the parasphenoid enclose the optic foramina.
11. The subtemporal fossa is noticed in the pterotic and the exoccipital for the insertion of the hyobranchial muscles.
12. The upper jaw shows a large preopercular which carries the mandibular sensory canal; from the temporal canal there may be a canal running in the opercular to reach the preopercular. The lower jaw shows the four typical bones, viz., the dentary, the angular, the retroarticular and the sesamoid angular.

13. The hyobranchial apparatus shows 3-4 copulae, two hypohyals, three hypobranchs and two pharyngobranchs. The fifth ceratobranchi carries a number of curved teeth.
14. The Weberian ossicles are not covered by the extensions of the neura arches of the vertebrae; the intercalarium articulates mesially with the second centrum. The tripus is large, sickle-shaped and articulates mesially with the third centrum and the posterior process comes in contact with the anterior part of the bifid gasbladder.
15. The caudal fin skeleton shows an urostyle projecting dorsally from the last centrum with the hypurals below; epurals and hypurals are also contributed by the two vertebrae behind to support the fin rays.

Psilorhynchus, while disclosing a number of cyprinid features shows quite few in which it is distinctive. These may have been developed in response to life in fast-running brooks or to a life of burrowing in sand, which, therefore, are adaptive. Whatever may be the causes, *Psilorhynchus* in possessing these distinctive characters stands apart from the other members of the family Cyprinidae in which it was included by Regan (1911) and by Berg (1940).

Psilorhynchus exhibits the following cyprinid characters along with *Parapsilorhynchus*:

1. The large supraethmoid is immovably articulated with the frontals.
2. The pre-ethmoids give articulation to the palatine.
3. The premaxillae show rostral processes.
4. The exoccipitals roof the foramen magnum and show lateral fontanels.
5. The ventral subtemporal fossa gives attachment to the hyobranchial muscles.
6. The basioccipital shows a bony process for the attachment of a horny pad and a pharyngeal process.
7. The hyobranchial apparatus shows only two pairs of pharyngobranchs.

It may not be out of place here to state that *Gyrinocheilus* (Ramaswami, 1952*a*, in press), which is also a denizen of hillstreams does not show so many cyprinine features in its skull structure.

Psilorhynchus shows the following features in which it differs from the Cyprinidae in general and *Parapsilorhynchus* in particular:

1. The rostral process of the maxilla does not project to form a fork for the premaxilla.
2. The palatine is elongated and forms laterally an articulation with the lacrimorostral.
3. The possession of a unique ethmoid-frontal fontanel.
4. The lateral ethmoid is devoid of lateral processes.
5. The extraordinary growth of the frontals laterally and the absence of a supraorbital.
6. The enlargement of the lacrimal and of the jugal and the former forming a composite lacrimorostral.
7. The hyomandibula has a single facet for articulation with the sphenotic.
8. The presence of an elongated basihyal in the hyoid cornu and the possession of a single pair of hypobranchs and of the fifth ceratobranchial showing only four teeth arranged in a row as described by Hora (1925).

The features enumerated above are sufficiently distinctive to warrant the separation of *Psilorhynchus* from the Cyprinidae and to make it the type of the family Psilorhynchidae as has been done by Hora (1925). It has not been possible for me to find out which cyprinid genus gave rise to a form like *Psilorhynchus* and I have already pointed out that *Psilorhynchus* differs from *Parapsilorhynchus* in far too

many characters and therefore, the latter while showing the parallel external modifications also noticed in *Psilorhynchus*, is a typical cyprinid and cannot be considered as the progenitor of the former.

It is clear from the foregoing study that *Gyrinocheilus*, another hillstream species which I have studied and reported upon (Ramaswami, 1952*a*, in press) must have branched off early from the cyprinoid stock since it exhibits a few cyprinid features, while *Psilorhynchus* in showing a larger number of cyprinid characters must have branched off later. It must be stressed here that in the structure of the Weberian apparatus, *Gyrinocheilus* is more catostomid while *Psilorhynchus* shows more nemachiline and homalopterid affinities.

Acknowledgments.

I am thankful to the Council of the National Institute of Sciences of India for the award of a senior fellowship to me. To Professor B. R. Seshachar, I am also very thankful for providing me with laboratory facilities. I am also deeply grateful to Dr. S. L. Hora, Director, Zoological Survey of India, Calcutta, for the gift of specimens and for the many helpful discussions I have had with him in the preparation of these papers.

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Key to Lettering.

af., articular facet of the quadrate with lower jaw; *an.*, angular; *ap.*, articular facet of the entopterygoid; *apv.*, anterior process of prevomer; *aup.*, auricular process; *bh.*, basihyal; *bo.*, basioccipital; *c.*, unossified cartilage; c_1 c_4 copulae 1-4; cb_1, cb_4, cb_5, ceratobranchs 1, 4, 5; *cc.*, commissure between supraorbital canals; *ce.*, centrum; ce_1, first centrum; *ch.*, ceratohyal; *co.*, occipital condyle; *d.*, dentary; *dlr.*, dorsolateral processes of median rostral; *dpm.*, dorsal process of maxilla; eb_1 eb_4, epibranchials 1-4; *ecp.*, ectopterygoid; *enp.*, entopterygoid; *enp'.*, entopterygoid process of palatine; *eo.*, exoccipital; *ep.*, epiphysis; *epo.*, epiotic; *epu.*, epural; *et.*, ethmoid; *f.*, exoccipital fontanel; *ff.*, ethmoid-frontal fontanel; *fr.*, frontal; *fr'.*, supraorbital extension of frontal; *gb.*, gasbladder; hb_1, hypobranchial 1; *hf.*, hypoglossal foramen; hh_1, hh_2, hypohyals 1, 2; *hp.*, bony plate for horny pad; hu_1 hu_7, hypurals 1-7; *hy.*, hyomandibula; *ic.*, intercalarium; *io.*, interopercular; *ios'.*, independent sensory canal ossicle; *jf.*, jugular foramen; *la.*, lacrimo-rostral; *les.*, lateral extrascapular; *let.*, *let'*, lateral ethmoid; *llp.*, lateral limb of premaxilla; *lm.*, branch to mandibular canal; *lma.*, lateral limb of maxilla; *lo.*, lateral opening in the dorsal rib of second vertebra; *lp.*, palatine process of lacrimo-rostral; *lpm.*, maxillary process for ligament; *lr.*, lacrimorostral; *lsc.*, lateral semicircular canal; *max.*, maxilla; *mc.*, Meckel's cartilage; *mp.*, metapterygoid; *mr.*, median rostral; *n.*, nasal; *na.*, neural arch; *o.*, orifice in the dentary; *oa.*, opercular arm, *oe.*, outline of ethmoid; *of.*, optic foramen; *ohy.*, outline of hyomandibular; *ole.*, outline of lateral ethmoid; *op.*, opercular; *opa.*, outline of palatine; *opar.*, outline of parietal; *opas.*, outline of parasphenoid; *ope.*, outline of pre-ethmoid; *opt.*, outline of pterotic; *or.*, orifice in the dorsal rib; *os.*, orbitosphenoid; *osf.*, outline of subtemporal fossa; *oss.*, os suspensoria; *otr.*, outline of tripus; ot_2, outline of dorsal rib 2; *p.*, median ethmoid process; *pa.*, parietal; *pal.*, palatine; *pas.*, parasphenoid; pb_1, pb_2, pharyngobranchs 1, 2; *pet.*, pro-ethmoid; *pgb.*, posterior part of gasbladder; *pa.*, pterotic articular facet of hyomandibula; *php.*, pharyngeal process; *phy.*, articular facet for hyomandibula; *pls.*, pleurophenoid; *pmx.*, palatine process of maxilla; *pmx.*, premaxilla; *pmy.*, posterior myodome; *pop.*, preopercular; *ppe.*, posterior process of prevomer; *pro.*, prootic; *psc.*, posterior semicircular canal; *pt.*, post-temporal; *pte.*, pterotic; *pv.*, prevomer; *pvo.*, provomerine process of maxilla; *sa.*, sesamoid angular; *sc.*, sensory canal in lacrimorostral; *sca.*, scaphium; *scc.*, subcentral canal; *se.*, supraethmoid; *sh.*, sphenotic articular facet of hyomandibula; *shy.*, facet for hyomandibula; *sm.*, symphysis meckelii; *so.*, supraoccipital; so_2-so_5, supraorbitals 2-5; *soc.*, supraorbital canal; *sop.*, sensory canal in opercular; *spo.*, sensory canal in preopercular; *spr.*, sphenotic process; *st.*, supratemporal; *stf.*, subtemporal fossa; *suo.*, supraorbital; *sy.*, symplectic; *t.*, teeth; *tc.*, temporal canal; *tf.*, trigemino-facialis opening; tp_1, tp_2, dorsal ribs 1, 2; *tr.*, tripus; *uro.*, urostyle

STUDIES ON CYTOCHEMISTRY OF HORMONE ACTION.

PART IX—*Responses of the adreno-cortical alkaline phosphatase in the Guineapig to various hormones.*

By AMIYA B. KAR, *Ph.D., Senior Research Fellow, N.I.S.I., and* ASOK GHOSH, *M.Sc., Central Drugs Laboratory, Government of India, Calcutta.*

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INTRODUCTION.

The presence of alkaline phosphatase has been demonstrated cytochemically in the mammalian adrenal cortex and in that of the pigeon. In the mice embryos, the capsule and the glomerulosa give a positive reaction for the enzyme but the rest of the gland is entirely negative for the phosphatase (Kabat and Furth, 1941). The same authors also observed that the adult human adrenal cortex exhibits maximum enzyme activity in the glomerulosa but the other two zones contain only moderate amounts of the enzyme. Bourne (1943) reported that the glomerulosa of the guineapig's adrenal cortex shows strong positive reactions for the phosphatase but he has not given any account of enzyme activity in the other two zones. Zorzoli and Stowell (1947) demonstrated the presence of alkaline phosphatase in the adrenal cortex of a number of mammals including the guineapig. The distribution of this enzyme in the cortex exhibits a sexual dimorphism in the rat (Dempsey *et al.*, 1949) and in the mouse (Elftman, 1947). Much more of the enzyme is present in the male than in the female. Dempsey *et al.* (1949) observed that after hypophysectomy the phosphatase disappears from the fasciculata and the reticularis of the rat's adrenal cortex but persists in the zona glomerulosa. Replacement therapy with whole pituitary powder causes a reappearance of the enzyme and a return to a condition approximating that of the normal gland. Soulairac *et al.* (1949) reported that castration caused considerable inhibition of cortical phosphatase activity in the rat. Androgen therapy in castrated animals evoked marked augmentation of phosphatase activity but estradiol benzoate and desoxycorticosterone acetate were less effective for this purpose. Elftman (1947) noted that alkaline phosphatase was absent from the adrenal cortex of the castrated male, the ovariectomised female and the immature male mice. Treatment of such animals with testosterone propionate resulted in the reappearance of the cortical phosphatase.

In the pigeon there are considerable amounts of alkaline phosphatase in the adrenal cortical strands located in the central region of the gland but in the peripheral cortical masses there is very little enzyme activity. Treatment with estrogen or androgen caused a reduction in the cortical phosphatase activity (Kar, 1950*a*). Progesterone or desoxycorticosterone acetate administrations were, however, associated with a pronounced augmentation of enzyme activity in the cortex of this species (Kar, 1951).

In the present paper an attempt has been made to study in detail the distribution and concentration of alkaline phosphatase in the adrenal cortex of the normal guineapigs, and to determine whether cortical phosphatase responded to various hormone treatments.

Experimental Procedure.

Adult male guineapigs were used in this study. A total of 28 animals were taken of which a group of 4 was left uninjected to serve as controls. The remaining 24 guineapigs were allotted in groups of 4 animals each for receiving hormone treatments. All of them were kept in cages under uniform husbandry conditions throughout the duration of the experimental period.

Steroid hormones used in this study were testosterone propionate, progesterone, estradiol dipropionate, diethylstilbestrol and desoxycorticosterone acetate, and the only non-steroid hormone used was serum gonadotrophin. Three injections of each hormone were given to a particular group of animals over a period of 7 days. The steroid hormones were dissolved in sterile sesame oil with the exception of diethylstilbestrol which was administered in an alcoholic solution diluted with 10% physiological saline according to the method of Kar (1947). Testosterone propionate was injected at the rate of 12·5 mgm. per treatment. The dosage for the rest of the steroid hormones, however, was 5 mgm. per injection. Serum gonadotrophin ('Gestyl', Organon Laboratories) dissolved in sterile distilled water, was administered in a dosage of 400 i.u. per injection.

Autopsy followed 24 hours after the final injections. The adrenals were carefully dissected out and fixed immediately in chilled 80% ethyl alcohol and in 10% formol-saline. After dehydration and imbedding in paraffin serial sections were prepared 6 microns in thickness. The tissue fixed in formol-saline was stained with Ehrlich's hematoxylin followed by alcoholic eosin. The sections of the adrenal fixed in ethyl alcohol were incubated in sodium glycerophosphate substrate according to the technique of Gomori (1941) for the demonstration of alkaline phosphatase. The sites of phosphatase activity in the tissue sections are marked by the deposition of cobalt sulphide in fine black granules. In order to allow critical observation of these deposits no counter-stain was used. The sections were dehydrated and mounted in the usual manner.

Results.

Controls. The nucleus of the connective tissue cells in the capsule gives a positive reaction for alkaline phosphatase. Phosphatase activity is also prominent in the endothelium of the capsular blood vessels. In agreement with the findings of Bourne (1943) we observed that in the glomerular zone marked concentration of the enzyme is visible in the component cells. Even the contour of these cells is made invisible by the granular deposits of cobalt sulphide. The entire glomerulosa appears as a dark band and quite well-marked from other cortical zones (Pl. III, fig. 1). In the zona fasciculata the nuclei stain quite intensely but in the cytoplasm the reaction is much less intense and the distribution of the enzyme appears to be rather irregular. The endothelium of the blood capillaries in the fascicular parenchyma also shows pronounced phosphatase activity. In the reticularis the nuclei show only a faint reaction but the cytoplasm and the endothelium of the blood capillaries in this region are virtually negative for the enzyme.

Androgen treatment. There is a pronounced reduction of phosphatase activity in the capsular elements. The connective tissue cells and the endothelium of the capsular blood-vessels are practically negative for the enzyme. In the glomerular zone the intensity of reactions appears to be the same as in the controls and the contour of the cells is totally obscured by cobalt sulphide deposits. In the subglomerular region of the fasciculata the distribution of the enzyme is similar to that in the controls but a definite reduction in phosphatase activity is evident in the rest of this zone (Pl. III, fig. 2). The endothelium of the blood capillaries in the fasciculata, however, continues to give a positive reaction for the phosphatase. Not even a trace of the enzyme is visible in the zona reticularis (Table I).

Progesterone treatment. The capsule gives an entirely negative reaction for the phosphatase. In the glomerulosa only moderate amounts of the enzyme are seen in the nuclei but the cytoplasmic phosphatase activity is practically nil. There is an overall reduction in enzyme activity in the fascicular zone (Pl. III, fig. 3). This enzymatic loss is evident in the fasciculor parenchymal cells as well as in the endothelium of the blood capillaries. The reticular zone continues to give a negative reaction for the phosphatase (Table I).

Desoxycorticosterone acetate treatment. The capsule gives a negative test for the phosphatase. Marked cellular atrophy is a notable histological feature of the cortex. In the glomerular zone a pronounced activity of the enzyme is visible but the reactions are less intense than in the control animals. This is evident from the fact that the glomerular masses with their component cells are clearly distinguishable even upon gross examination and do not appear as a dark homogeneous band as in the control animals (Pl. III, fig. 4). The zona fasciculata shows a marked reduction in phosphatase activity. The endothelium of the blood capillaries in this region also stains in a faint manner. The reticular zone is entirely small negative for the phosphatase (Table I).

TABLE I.

The Distribution of Alkaline Phosphatase in the Adrenal Cortex of normal and various hormone-treated Guineapigs

	Controls.	Androgen treated.	Progesterone treated.	DCA-treated.	Estradiol treated.	Stilbestrol-treated.	Gonadotrophic hormone-treated.
Capsule ..	+ +	+	−	−	−	−	−
Zona glomerulosa ..	+ +	+ +	+ ^{n}	+	+	+	+ ^{n}
Zona fasciculata							
Parenchymal cells ..	+ + ^{nn}	± ± ^{nn}	+	+	+	+ ^{n}(F)	+ (F)
Blood Capillaries .	+ +	+	+	+	+	−	.
Zona Reticularis ..	+ (F)^{n}	−	−	−			

Legend :— + + = Strong alkaline phosphatase activity.
+ = Reduced alkaline phosphatase activity.
− = No alkaline phosphatase activity.
± ± = Strong activity in the sub-glomerular zone but no activity in the rest of the zone.
n = Moderate activity only in the nuclei.
nn = Very strong activity only in the nuclei.
(F) = Slight activity.

Estradiol dipropionate treatment. The phosphatase activity in the capsule is practically nil. In the glomerular zone the distribution of the enzyme is more or less similar to that in the DCA-treated animals. The fasciculata shows marked vacuolisation of the parenchymal cells particularly in the region adjacent to the reticularis. There is a definite reduction in phosphatase activity in this zone (Pl. IV, fig. 5). The endothelium of the blood capillaries in the fasciculata is also virtually negative for the enzyme. The reticularis is conspicuous by the absence of phosphatase activity (Table I).

Diethylstilbestrol treatment. No trace of the enzyme is visible in the capsule. Atrophic changes are evident in the cortex and an overall reduction in phosphatase activity is clearly distinguishable. In the glomerulosa moderate amounts of the enzyme are present. Only slight nuclear phosphatase activity is present in the fasciculata (Pl. IV, fig. 6). The endothelium of the blood capillaries in this zone is

also negative for the enzyme. No phosphatase activity is seen in the reticularis (Table I).

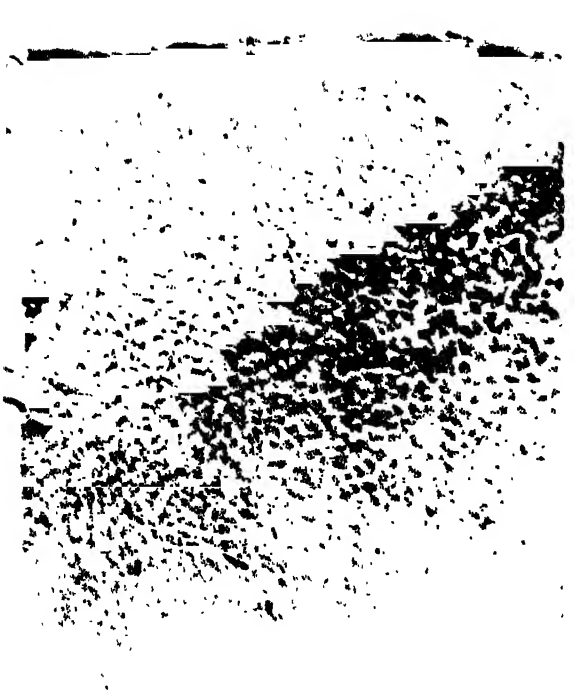
Gonadotrophic hormone treatment. No phosphatase activity is visible in the capsule. There is a marked reduction in enzyme activity in the different zones. In the glomerulosa moderate amounts of phosphatase are present only in the nuclei but the cytoplasmic enzyme activity is practically nil. The fascicular zone is virtually devoid of phosphatase activity (Pl. IV, fig. 7). The enzyme is totally absent in the reticularis (Table I).

Discussion.

The pattern of distribution of alkaline phosphatase in the adrenal cortex of the guineapig differs in several respects from that in the rat and the mouse. In the rat considerable quantities of the enzyme occur in the glomerular zone, where the endothelium of the sinusoids stains quite intensely but the parenchymal cells show only moderate reactions in the nucleus. The fasciculata and the reticularis, however, exhibit uniform phosphatase activity (Dempsey *et al*., 1949; Soulairac *et al*., 1949). In the mouse (Elftman, 1947), the glomerulosa shows negative reactions for the enzyme but the fasciculata and the reticularis give strong positive reactions for the phosphatase. The distribution of the enzyme, however, is somewhat different in the embryonic mouse where the glomerulosa shows intense phosphatase activity but the other zones are entirely negative for the enzyme (Kabat and Furth, 1941). The glomerulosa of the adult human adrenal cortex exhibits pronounced phosphatase activity but the fasciculata and the reticularis contain only moderate amounts of the enzyme (Kabat and Furth, 1941). In contrast to these pictures, the glomerulosa of the guineapig's cortex shows more spectacular phosphatase activity but in the fasciculata the reactions are undoubtedly less intense while in the reticularis the enzyme activity is almost negligible. It is, therefore, evident that the distribution and concentration of alkaline phosphatase in the adrenal cortex show great deal of species variability in the mammals, and in this connection we feel that work on other mammalian species may reveal some hitherto unknown facts regarding the distribution of this enzyme in the cortex.

The enzymatic response of the individual adreno-cortical zones in the guineapig to various hormones is an item of considerable interest. Our results clearly demonstrate that androgen treatment alone retains normal Gomori reactions in the glomerulosa which we may recall here, is the zone of maximum phosphatase activity, but other hormones cause definite reduction in enzymeactivity in this zone (see Table I). A uniform loss of phosphatase activity is, however, encountered in the fasciculata of all the treated groups, whereas the reticular enzyme shows practically no response to various hormonal treatments. Thus, it is evident that the action of various hormones on cortical phosphatase activity in this species is in a general sense, inhibitory. In this connection, we would like to point out once again that the effect of androgen is somewhat different from other hormones since it does not cause any reduction in glomerular enzyme activity but with regard to its action on other cortical zones it falls well in line with the rest of the hormones in our list. Possibly, this effectiveness of androgen in retaining the glomerular phosphatase activity is ascribable to the fact that it is the homologous sexual hormone of our material. However, this explanation is only tentative and we suggest that its validity should be tested experimentally with female guineapigs as the material.

Kar (1950) observed that treatment with estrogen or androgen reduces cortical phosphatase activity in the pigeon, but the degree of this reduction is more pronounced in birds receiving estrogen than in the androgen-treated birds. Progesterone or DCA administrations, on the other hand, cause a marked augmentation of enzyme activity in the cortex of this species (Kar, 1951). The response of the adreno-cortical alkaline phosphatase in the guineapig to estrogen or androgen is in



a sense, similar to that in the pigeon. In this mammalian species also we find that the gonadal hormones cause an overall reduction in cortical enzyme activity but here again, the effect of androgen appears to be less severe than that of the estrogen. The luteoid and the corticoid, however, have altogether different effects. These two hormones definitely inhibit the phosphatase activity of the guineapig's cortex and, therefore, it is evident that their actions are totally unlike in the two vertebrate species studied by us.

Summary.

The distribution of alkaline phosphatase has been studied cytochemically in the adrenal cortex of normal and of various hormone treated guineapigs. In the normal guineapigs spectacular enzyme activity is visible in the glomerular zone but the fasciculata contains only moderate amounts of the phosphatase. The reticularis gives almost negative reactions for the enzyme. Hormonal treatments cause an overall reduction in phosphatase activity in the cortex. The possible significance of this enzymatic reduction is pointed out and discussed.

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Explanation of Plates

(All figures are photomicrographs and are magnified × 70.)

Plate III

Fig. 1. Section through the adrenal cortex of a control guineapig. Note the spectacular phosphatase activity in the glomerular zone.

Fig. 2. Section through the adrenal cortex of an androgen-treated guineapig. Compare with fig. 1.

Fig. 3. Section through the adrenal cortex of a progesterone-treated guineapig. Note the loss of phosphatase activity from the glomerular and fascicular zones.

Fig. 4. Section through the adrenal cortex of a DCA-treated guineapig. Compare with figs. 1 and 3.

Plate IV

FIG. 5. Section through the adrenal cortex of an estradiol dipropionate-treated guineapig. Note the reduction in phosphatase activity from the glomerular and fascicular zones.

FIG. 6. Section through the adrenal cortex of a diethylstilbestrol-treated guineapig. Marked reduction in phosphatase activity is evident.

FIG. 7. Section through the adrenal cortex of a gonadotrophic hormone-treated guineapig. Note the pronounced reduction in phosphatase activity.

NATIONAL INSTITUTE OF SCIENCES OF INDIA

Seventeeth Anniversary General Meeting

The Seventeenth Anniversary General Meeting of the National Institute of Sciences of India was held at 10 a.m., on Tuesday, the 1st January, 1952, at the Presidency College, Calcutta.

PRESENT:

Dr. S. L. Hora, *President*, in the chair.
Dr. K. N. Bagchi, *Additional Vice-President.*
Prof. N. R. Dhar, *Additional Vice-President.*
Dr. J. N. Mukherjee, *Foreign Secretary.*
Prof. D. S. Kothari, Dr. H. S. Pruthi } *Secretaries.*

Prof. S. P. Agharkar.	Prof. K. P. Chattopadhyay.	Dr. G. C. Mitter.
Dr. J. B. Auden.	Dr. R. N. Chaudhuri.	Dr. P. C. Mitter.
Prof. K. N. Bahl.	Dr. K. A. Chowdhury.	Dr. B. P. Pal.
Prof. K. Banerjee.	Dr. S. Datta.	Dr. B. N. Prasad.
Prof. A. C. Banerji.	Dr. R. K. Dutta Roy.	Prof. H. Rakshit.
Prof. S. K. Banerji.	Mr. P. Evans.	Dr. H. N. Ray.
Dr. J. K. Basu.	Dr. J. Ghosh.	Dr. J. C. Ray.
Prof. N. M. Basu.	Dr. P. K. Ghosh.	Prof. P. Ray.
Dr. U. P. Basu.	Mr. S. Gupta.	Dr. S. K. Ray.
Dr. J. L. Bhaduri.	Dr. K. Jacob.	Prof. M. N. Saha.
Dr. P. N. Bhaduri.	Prof. A. C. Joshi.	Dr. P. B. Sarkar.
Prof. S. Bhagavantam.	Dr. M. S. Krishnan.	Prof. J. M. Sen.
Prof. D. M. Bose.	Dr. B. C. Kundu.	Prof. N. K. Sen.
Dr. N. K. Bose.	Prof. C. Mahadevan.	Prof. N. R. Sen.
Dr. P. K. Bose.	Prof. G. P. Majumdar.	Mr. V. P. Sondhi.
Prof. S. R. Bose.	Prof. R. C. Majumdar.	Dr. P. L. Srivastava.
Dr. S. K. Chakrabarti.	Dr. K. Mitra.	Prof. N. R. Tawde.
Prof. S. C. Chatterjee.	Prof. S. C. Mitra.	Dr. A. C. Ukil.

Besides Fellows, there was a large number of visitors present.

1. The minutes of the Seventeenth Annual General Meeting, held on October 5–6, 1951, were confirmed.

2. The President reported death of Sir Cyril S. Fox, Dr. M. Qureshi, Dr. K. Subramaniam and Mr. James Vail. A resolution of condolence was passed, all standing.

3. Dr. H. N. Ray was admitted as an Ordinary Fellow and signed the Register under provisions of Rule 13.

4 (*a*) The President appointed Prof. S. P. Agharkar and Prof. A. C. Banerji as scrutineers for the voting papers for the election of office-bearers and Members of Council for the year 1952.

As a result of scrutiny, the following were declared duly elected to the Council:—

President	Dr. S. L. Hora (Calcutta).
Vice-Presidents	Prof. K. N. Bahl (Lucknow). Prof. P. Parija (Cuttack).
Treasurer	Dr. B. P. Pal (Delhi).
Foreign Secretary	Prof. P. C. Mahalanobis (Calcutta).

Secretaries	Dr. H. S. Pruthi (Delhi). Prof. R. C. Majumdar (Delhi).
Editor of Publications	Prof. J. M. Sen (Calcutta).
Members of Council	Dr. S. P. Agharkar (Poona). Dr. J. L. Bhaduri (Calcutta). Prof. H. J. Bhabha (Bombay). Prof. S. Bhagavantam (Hyderabad). Prof. B. B. Dey (Madras). Dr. B. C. Guha (Calcutta). Dr. V. R. Khanolkar (Bombay). Prof. D. S. Kothari (Delhi). Dr. C. Mahadevan (Waltair). Prof. S. K. Mitra (Calcutta). Dr. B. Mukerji (Lucknow). Dr. V. G. Panse (Delhi). Dr. Mata Prasad (Bombay). Dr. L. A. Ramdas (Poona). Prof. M. N. Saha (Calcutta). Dr. V. Subrahmanyan (Mysore). Dr. K. Venkataraman (Bombay).

4(*b*) The President also announced that the following were nominated by the Government of India and other co-operating academies to serve on the Council of the Institute for 1952 as their representatives:—

Government of India	Dr. C. G. Pandit (Delhi).
Asiatic Society	Dr. K. N. Bagchi (Additional Vice-President, Calcutta). Dr. A. C. Ukil (Additional Member, Calcutta).
National Academy of Sciences (India)	Prof. A. C. Banerji (Additional Vice-President, Allahabad). Dr. P. L. Srivastava (Additional Member, Allahabad).
Indian Science Congress Association	Dr. J. N. Mukherjee (Additional Vice-President, Roorkee). Prof. B. Sanjiva Rao (Additional Member, Bangalore).

5. The President announced that as a result of scrutiny of voting papers received from Fellows, the following were duly elected Ordinary and Honorary Fellows of the Institute:—

Ordinary Fellows.

Banerjee, Sachchidananda, M.Sc., M.B.B.S., D.Sc., *Professor of Physiology, Presidency College, Calcutta.* Distinguished for his work on effect of vitamins B and C on metabolism with reference to diabetes.

Dessau, Gabor, Dr.Ing. (Rome), (*formerly geophysicist, Geological Survey of India*), *Ufficio Geologico, Rome.* Distinguished for his work on mineralogical and geophysical studies.

Mehra, Pran Nath, D.Sc., *Head of the Department of Botany, Punjab (I) University, Amritsar.* Distinguished for his work in the field of cytology and embryology in gymnosperms, pteridophytes and luriworts.

Panikkar, N. Kesava, M.A., D.Sc., *Chief Research Officer, Central Marine Fisheries Research Station, P.O. Mandapam Camp, S. India.* Distinguished for his work on Indian sea anemones, ecology of brackish waters at Madras and osmotic and ionic regulations in the Crustacea.

Parthasarathy, S., D.Sc., *Assistant Director, National Physical Laboratory of India, New Delhi.* Distinguished for his work on ultrasonics and light scattering.

Pramanik, S. K., M.Sc., Ph.D., D.I.C., *Deputy Director-General of Observatories, Meteorological Office, Poona 5.* Distinguished for his work on meteorological problems.

Raychaudhuri, Satyaprasad, Ph.D., D.Sc., F.R.I.C., *Officer on Special Duty, Soil Conservation, Ministry of Agriculture, Government of India, New Delhi.* Distinguished for his work on various problems in electro-chemistry of colloids activated charcoal, soil classification and soil survey, etc.

Saksena, Ram Kumar, M.Sc., Doc. es Sc., *Reader in Botany, Allahabad University Allahabad.* Distinguished for his work on physiology, cytology and life histories of many species of pythium and some other phycomycetes.

Sen, Bibhutibhushan, D.Sc., *Principal, Hooghly Mohsin College, Chinsurah, West Bengal.* Distinghished for his work in the mathematical theory of elasticity.

Shah, Swarupchand Mohanlal, M.A., Ph.D., *Reader in Mathematics, Muslim University, Aligarh.* Distinguished for his work in the theory of integral functions, theory of numbers and difference equations.

Singh, Inderjit, Ph.D., L.R.C.P., M.R.C.S., M.B.B.S., F.A.S., *Professor of Physiology, Agra Medical College, Agra.* Distinguished for his work on respiration-intravenous oxygen therapy, unstriated muscle and blackwater fever.

Thapar, Govind Singh, M.Sc., Ph.D., *Reader in Zoology, Lucknow University, Lucknow.* Distinguished for his work on helminthology.

Uppal, Harbans Lal, M.Sc., Ph.D., *Deputy Director, Irrigation Research, Hydraulic Research Station, Malakpur.* Distinguished for his work on river training, design of weirs, subsoil seepage and hydrautomats.

Honorary Fellows.

Prof. Dr. Bernardo A. Houssay, N. L., *Instituto de Biologia y Medicina Experimental, Costa Rica 4185, Buenos Aires, South America.*

Mark, Hermann, *Director of Polymer Research, Brooklyn Polytechnic Institute, Brooklyn, U.S.A.*

6. The President delivered his Address on 'Adaptation and Evolution' (see page 161).

7 (*a*) The following communication was made by Dr. H. N. Ray and discussed:—

A new finding in the development stages of *Babesia bigamina.*

(*b*) In the absence of authors, the following papers were taken as read:—

(1) *A systematic account of the Chaetognatha of the Indian Coastal waters, with observations on their seasonal fluctuations along the Malabar Coast.* By P. C. George and communicated by Dr. H. S. Rao.

(2) *Skull of Cyprinoid Fishes in relation to phylogenetic Studies. Part III. The skull of Homalopterid Fishes. Part IV. The skull of Gastromyzonid Fishes.* By L. S. Ramaswami and communicated by Dr. S. L. Hora.

(3) *Evolution and distribution of the Glyptosternoid Fishes of the Family Sisoridae (Order: Siluroidea).* By S. L. Hora and E. G. Silas;

(4) *The optical principles of the low Angle.* By N. N. Gupta and communicated by Prof. K. Banerjee;

(5) *The complex Band Spectrum of diatomic manganese chloride in the visible region.* By P. Tiruvenganna Rao and communicated by Prof. K. Rangadhama Rao.

(6) *Scattering of Electrons and contrast in the electron-micrographs of shadow-cast specimens.* By A. K. Chaudhuri and communicated by Prof. M. N. Saha.

(7) *The adiabatic oscillations of a particular model of the variable Star.* By R. S. Kushwaha and communicated by Prof. A. C. Banerji.

(8) *A note on the relation between maximum Pressure and short-term Pressure.* By N. S. Venkatesan and communicated by Dr. R. S. Varma.

(All these papers have been recommended for publication in the *Proceedings* of the Institute.)

8. A Symposium on 'Soil Research in India' organized by Dr. J. N. Mukherjee was held from 2 to 3-30 p.m.

The Symposium continued on 2nd January, from 2-30 to 3-30 p.m.

PRESIDENTIAL ADDRESS: ADAPTATION AND EVOLUTION.*

By SUNDER LAL HORA, *D.Sc., F.R.S.E., C.M.Z.S., F.A.S., F.N.I.*,
Director, Zoological Survey of India, Calcutta.

FELLOWS OF THE NATIONAL INSTITUTE, DISTINGUISHED VISITORS, LADIES AND GENTLEMEN,

The Constitution of the National Institute enjoins on the President to review the work of the Institute at the Annual General Meeting and to deliver his Presidential Address at the Anniversary General Meeting. Though the scope of the remarks to be made at the Annual General Meeting is limited, the President is happily left to exercise his own choice of the subject for the Anniversary General Meeting. On this occasion, it has been a practice that the President addresses the Fellows on a subject of his research or intensive study. Since this meeting is linked with the session of the Indian Science Congress, I shall also abide by the past practice.

At the Annual General Meeting of the National Institute of Sciences of India, held in October last, I reviewed the work of the Institute and put forward certain suggestions for implementing the objects for which the National Institute was established. Towards the end of that address, I drew the attention of the Fellows to the serious neglect in India of the biological sciences, which have an important bearing on national welfare, especially when increased production of food, improvement of health and raising of the nutritional standards of the Indian masses are some of the most urgent needs of the country. It was my intention to follow up this subject and speak this morning on the rôle of the biological sciences in the future development and progress of India and I had, in fact, collected notes from several experts in different branches of biology, more competent than myself to appraise the value of biological sciences in national welfare. But, I have found that the subject is so vast and its various ramifications so important that justice could not be done to it in a single address. It is accordingly being suggested that it should be treated as a subject for a Symposium under the auspices of the National Institute. The Council's interest in the development of biological sciences will be evident from the following resolution passed unanimously at its October meeting:

> 'Realizing that there is considerable scope for fundamental research in the field of Biological Sciences and for co-ordinating research in them on an all-India basis, and also realizing financial and other limitations for the establishment of full-fledged new National Laboratories under the present circumstances, it is recommended that steps be taken to develop "Wings" for these purposes in suitable existing institutes and financed from central revenues.'

This and other resolutions explaining the scope of 'Wings' have been forwarded to the Ministry of Natural Resources and Scientific Research and the hope has been expressed that, when funds permit and the various 'Wings' are sufficiently stabilized, the question of establishing a unified and centrally controlled National Biological Institute will be taken up, of which the 'Wings' in different subjects will form the components. It is my earnest desire and sincere hope that the Government of India will pay sympathetic consideration to this suggestion of the National Institute of Sciences of India; for therein lies the future competence to deal with for most of

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* Delivered at the Anniversary Meeting of the National Institute of Sciences of India, held at Calcutta on the 1st January, 1952.

the ills of this country, constantly in the grip of starvation and ill-health but not so mindful of rapid increases in population. The importance of theoretical or fundamental research cannot be exaggerated, as the question of practical application can arise only after the theory is known. Today, therefore, I shall address you on some most recent developments of a very important biological concept of the rôle of adaptations in evolution.

Adaptation and Evolution

In selecting an alternative subject for my address, I have been greatly influenced by the correspondence in the recent issues of *Nature* received in this country during the last six weeks or so. In the issue of September 8, 1951, Dr. A. J. Cain raised the question of the value of 'So-called Non-adaptive or Neutral Characters in Evolution'; and, in my view, rightly concluded 'that those characters or variation patterns that have been described as non-adaptive or random should properly be described as "uninvestigated". One must not assume randomness (or selection) without proof'. Professor G. S. Carter (1951), in commenting on Dr. Cain's observations, suggests that we must accept 'non-adaptive evolution as theoretically possible, and, until it is shown to play no significant part in natural differentiation we must give it a place in our general view of evolutionary theory'.

It seems to me that there is considerable confusion in dealing with the subject of 'Adaptations' and their significance in organic evolution. In fact, political ideologies have become intertwined round this subject with the result that in certain countries freedom of thought in science is now denied to individuals who hold views for or against adaptations and inheritance of acquired characters.

I attempted to elucidate the problem of adaptations in 1930, when dealing with the ecology, bionomics and evolution of the torrential fauna. I asserted then 'that evolution is no more than the adaptation of organisms to environment' and that 'Structural modifications are produced through changes of functions'. Further studies, both in the field and the laboratory, have now convinced me that changes in environment initiate functional changes in organisms as a first step in evolution and that such functional changes ultimately lead to structural modifications. The repetition of this sequence of events at shorter or longer intervals has determined the rate of evolution during various epochs of the earth's history and among diverse groups of animals. To substantiate this hypothesis, I shall first refer to some previous observations of other workers and then place before you the nature of the evidence that has influenced me to come to these conclusions:

The traditional viewpoint

In his Bancroft Memorial Lecture, Professor Frederic Wood Jones (1931) gave a comprehensive historical review of the concept of adaptations and showed how this point of view has been changing through the centuries. He starts with the Galenical Outlook of the 2nd Century A.D. The earliest clear conception of the phenomenon of adaptations is, however, given in *Suśrutasaṃhita* where the correlation between the form of fishes and their respective environments is discussed (*vide* Hora, 1935). A free translation of the relevant Sanskrit passage reads thus:—

> The river fish are bulky in the middle because they move with their head and tail; the lake and tank fish are similar to the above but are characterized by a relatively smaller head; the spring and pool fish, as they have not much space to move about, are extremely deep behind the head; the fishes of the torrents are traditionally well-known by the possession of two characteristics, the greatly flattened body on account of their habit of crawling with the chest, and a relatively reduced anterior part of the body.

Unfortunately the age of *Suśrutasaṃhita* is not at present definitely known. Some scholars place it as early as 600 B.C., while others consider the present text

only as old as 200 to 500 A.D. Whatever may be the date of this work, it can be stated without any fear of contradiction that the concept of adaptation brought about by environmental factors was well-known to the ancient Hindus.

Annandale on adaptations.

In the study of adaptive evolution, the most outstanding work of the late Dr. N. Annandale seems to have been lamentably ignored but modern students will find in it a wealth of accurate information unrivalled for its clarity of thought and lucidity of expression. He was the foremost naturalist of his time and it was always his habit to study animals against the background of their respective environments. I shall here draw attention to two of his papers written just before his death in April 1924. Firstly, in his Presidential Address to the Eleventh Indian Science Congress in 1924 on 'Evolution—Convergent and Divergent', he stated that 'A simple explanation (of evolution) becomes more and more impossible and environment with its unlimited gradations assumes an ever greater importance. *Indeed it seems hardly too much to say that evolution is ultimately no more than adaptation of organisms to environment*'. (Italics are mine.) Again, in dealing with the evolution of the shell-sculpture in fresh-water snails of the family Viviparidae (1924*a*), he stated:

> 'My explanation of the phenomena discussed in this paper implies an acceptance of the doctrine of the survival of the fittest and at the same time a firm belief in the inheritance of one kind of acquired character. The traumatic injury of an individual can probably not affect the race, *but unless we assume that the long-continued and gradual influence of environment can do so it is difficult to see how adaptive characters have ever arisen.* The very existence of such characters may be denied by observers in a laboratory or a garden plot, but in tropical nature they are continually being forced on the notice of the field zoologist'. (Italics are mine.)

Doctrine of the survival of the fittest

Annandale's acceptance of the doctrine of the survival of the fittest, it will be observed, is not Darwinian for variations in the sense used by him are not random nor are they selected by Nature from any haphazard lot but they are due to the 'long-continued and gradual influence of environment' and are thus acquired by the individual as an adaptation towards the external conditions of its existence. Nature is undoubtedly a very hard task master and, whatever may be the source of variations, the doctrine of the survival of the fittest must hold good. What I believe is that the animal, while still capable of growth, responds to the new situation by a slight alteration of growth; and, having thus responded successfully hands over to the next generation an increased capacity to respond, which is continually increased generation after generation till it becomes firmly engraved on the hereditary power. This implies that there are no random variations and that 'variation is due to the different efficacy with which the individual responds to the influence of the environment and that this is due to the varying degree of *vigour* possessed by the animal and that vigour is the one thing which varies continually (probably due, I think, to the position of the germ-cell in the genital organ and its varying amount of nourishment) and that natural selection chooses not the random variation but the individual which is most responsive to the environment' (quoted from a letter of Professor E. W. MacBride to the writer, dated November 8, 1928). The point made out by Professor MacBride is that one has not to consider the survival value of a character under study but of the individual as a whole, for an organism is a combination of many characters showing responses to unlimited factors in its environment.

Adaptations are functional modifications

From what is stated above, it is implicit that all adaptations are functional and that when in the economy of life of an organism a particular morphological structure becomes non-functional, it persists for some time as a vestigeal organ. I shall

take here a very simple case of the modification of the air-bladder in hill-stream fishes. In most of the sluggish-water Cyprinid fishes, the two-chambered air-bladder is well-developed to serve a hydrostatic function. When a fish enters fast-flowing waters, buoyancy will be a disadvantage, for the fish must tend to live near the bottom or in fact it must take to the ground habit of life. We have various species of *Garra*, for instance, in which we can correlate the reduction of the air-bladder with the development of the adhesive disc and the swiftness of the water in which the various species live (Hora, 1921). In loaches of the genus *Nemachilus*, I (1930*a*) showed how the air-bladder becomes reduced under the influence of stronger and stronger currents and when the air-bladder is so reduced and enclosed in bone that it cannot respond to the external environmental conditions, it is left alone as a vestigeal organ. Thus a new air-bladder is developed in species of *Nemachilus* (= *Diplophysa*) which inhabit lakes or other deeper waters at high altitudes in Central Asia. Here we have a remarkable instance of the normal functional air-bladder undergoing structural modifications induced by the environment to ensure proper adjustment of its functions to the needs of the organism concerned. So long as it is sufficiently plastic, it goes on reacting to the external conditions of its existence, but the moment it is reduced beyond a certain stage it becomes vestigeal and if there is need for such a structure for the functional activities of the fish, a new air-bladder makes its appearance. Moreover, though functionally the new bladder may be similar to the old normal bladder, morphologically it is different, for the pneumatic duct in the normal bladder opens in the constriction between the two chambers while in the new bladder it opens at the anterior end. What differences in the environmental factors or genetical variations have produced these dissimilarities, it is not possible for me to say, for the finer gradations between the two environments still remain to be investigated.

The reduction of the air-bladder in hill-stream fishes is correlated with the ground habit of life. This assumption is justified, for whichever group of fishes, Carps, Catfishes, Gobies, etc., has entered swift currents, the fate of the bladder has been the same. Furthermore, if the ground habit is a necessity in other types of habitats, such as the estuaries, marshes, etc., the air-bladder becomes reduced in more or less the same way as in hill-streams. It follows that adaptations are functional irrespective of types of environment.

Animal plasticity and environment

A remarkable instance of structural modifications was observed among the two groups of individuals of a species of fish, *Acanthophthalmus pangia* (Hamilton), living within a short distance of each other in the same stream by the writer (1930*b*) long ago. In one set of specimens, collected from among the débris at the bottom of a pool, the pelvic fins were absent (genus *Apua* Blyth), while in the other set collected from among the pebbles in a swift current, the paired pelvic fins were present (genus *Acanthophthalmus* Blkr.). Those whose interest is to study characters only have already pronounced their judgment by keeping apart the two sets of individuals in two different genera and thereby confusing the issues of evolution. We have seen the same taxonomic treatment accorded to the species of *Nemachilus* that develop a new bladder, though still retaining the old as a vestigeal organ. My knowledge of the environment in both cases is yet too incomplete to explain these adaptations.

Study of environment neglected

Whenever I have studied the taxonomy of a group of fishes, which I have observed alive in nature, it has always been possible for me to understand the functional values of the taxonomic characters, however trivial they may appear in separating species or subspecies. But, though I am trained to describe in the minutest detail the characters of an organism, I am afraid I have always been handicapped in describing the environment in the same detail, for it entails an advanced knowledge of engineering, physics and chemistry. As

Adaptation' signifies correlation of an animal with its habitat, the study of an animal alone, however detailed, without a similar study of the environment cannot lead to the proper understanding of this universal phenomenon.

For evaluating factors responsible for evolutionary changes, it is thus necessary to know the details of the environment. Though, in a humble way, I have attempted such a study in reference to a few habitats of animals, I am fully conscious that they are very imperfect indeed. As early as December 30, 1928, Dr. E. J. Allen wrote to me in reference to my studies on the torrential fauna already referred to:

> 'The work is very interesting indeed, and the more we can have of the same kind the better. I hope too you will try to start some experimental work, and try and find out "how it is done". It is all very fundamental.'

Only recently, on the 3rd October, 1951, an American friend suggested that it would add significantly to the value of my work if someone could go out in the field and measure water speed to permit correlation of the development of adhesive devices with proportionately faster flow.

Here I must confess that I have never seriously attempted such field studies, which require a detailed knowledge of hydrostatics and hydrodynamics, though only such studies could enable the evaluation of the influence of rapid currents in reference to graded evolution of structures. However, Dodds and Hisaw (1924) have discussed the adaptations exhibited by certain Mayfly nymphs of *Baetis* for life in swift currents, and have shown that a direct correlation exists between the swiftness of the current and the degree of reduction of the median caudal seta. *B. tricaudatus*, with 3 tail setae, lives in currents flowing at the rate of 5 feet per second; *B. intermedius*, with a shorter middle seta, lives in waters flowing as fast as 8 feet per second and *B. bicaudatus*, with the middle seta vestigeal, lives in places where the water flows at the rate of 10 feet per second. The reduction of the middle seta ensures proper stream-lining of the body to present a stream-line form to the swift current.

Difficulties of studying environment biologically

Though a physical scientist may be able to study in detail the physico-chemical factors in an environment, he may not be able to evaluate their biological significance with reference to the fauna under study, unless he is also a trained biologist. The study of adaptations therefore, requires a team-work approach and I think it will be worthwhile to start this work as a co-operative project by biologists and physicists. Whenever I have been able to get the assistance of a physical scientist, the apparent biological riddles have been resolved into simple elementary facts. For example, in Blepharocerid larvae from torrential streams, I was surprised to see that some had long spinous processes on them, while in others the surface was smooth. In ordinary circumstances, the development of spines would be considered not only useless but distinctly harmful to the animal in a rushing torrent. Though it seemed to me a paradox, it was shown to me that under certain conditions such processes help to decrease resistance. For instance, it is known to the engineers that 'in some such bodies as spheres and cylinders, the law of resistance may change widely with comparatively small alterations in the conditions; thus, for example, at certain speeds the resistance of a sphere may actually be reduced by roughening the surface'. (Gibson, 1923.)

I shall refer here to another instance which baffled me for long. Certain Sisorid Catfishes, such as *Conta* Hora, *Glyptothorax* Blyth and *Laguvia* Hora, living in swift-flowing rocky streams have an adhesive apparatus formed of longitudinal folds of skin on the thorax while certain others, such as *Pseudecheneis* Blyth, *Propseudecheneis* Hora and *Parapseudecheneis* Hora, have developed transverse folds in the chest region (Hora, 1952*b*). After considerable study and thought,

it became clear that when a cylinderical fish enters swift currents, it will develop longitudinal folds along the ventral surface to increase friction, while a flattened fish will develop transverse folds. This view is strengthened by the fact that when the cylinderical fishes, as an adaptation to the ground habit of life on rocks in swift currents, become depressed and flattened and the function of adhesion is passed on to the paired fins, the outer rays become flattened and develop transverse adhesive folds.

The above two instances show that a biologist alone cannot properly interpret variations in structures, unless he understands the responsible physical factor or factors in the environment equally well.

Magnitude of adaptive variations

It is now conceded, even by geneticists, that 'adaptation is very unequally distributed through the several taxonomic ranks. In general it is considerable in the high ranks, slight or wanting in the low ranks' (Shull, 1951). According to this dictum, the characters that define classes, orders, families and genera have perhaps some adaptive significance, while those characterizing genera, species, and subspecies have rarely any adaptive importance. In my opinion, this merely indicates that we understand very little of the unlimited gradations in the environment against which only the minor characters of an animal can be equated. I have mostly worked on the taxonomy of hill-stream fishes during the last 32 years and have made extensive collections from all over India myself. I have not only collected fishes from mountain torrents, but have also tried to understand their ways of life through observations and simple experiments carried out in the field. In classifying these fishes right up to the subspecies rank, I can say with a considerable degree of confidence that even the so-called most insignificant characters, such as number and disposition of scales; number of rays in various fins and the shape of fins, nature of the mouth and associated structures, appendages in the axils of fins, etc., etc., have some adaptive significance when considered against the background of environmental factors. For instance, it has been observed over and over again that in fishes that adhere firmly to rocks by applying their ventral surface, the ventral portions of the gill-openings, being non-functional in such circumstances, gradually close up; and ultimately they are greatly reduced and are restricted to the dorsal surface above the pectoral fins. A critic from America has recently written to say that 'This is simply not true. Many Gobies which have adhesive discs and sit on the bottom have terrific gill clefts. My guess would be that Hora's fishes have their gill-openings restricted because they are living in such thoroughly oxygenated water and are not active and have, as a consequence, an easy time respirationally'. The adhesive disc of the Gobies is formed by the union of pelvic fins and the ventral surface of the body is, therefore, usually not closely applied to the substratum. Accordingly, in Gobies as a rule, there is no interference with the ventral extensions of the gill-openings. But when the Gobioid fishes enter torrential streams and the body becomes greatly flattened, the gill-openings are restricted to the sides and extend to the ventral surface for a short distance only (Hora, 1932*b*).

It is probably true that, when the gill-openings thus become restricted to the dorsal surface in hill-stream fishes, further reduction of their size is due to the highly oxygenated nature of the water. The adaptation that I have not yet been able to account for is the extensive nature of the gill-openings in the Chinese Homalopterid fish *Sinogastromyzon* Fang, in which the ventral surface and the paired fins do form an adhesive disc. Some observations on the respiratory mechanism of this fish will no doubt help in elucidating this adaptation. For the present, it can be included in the list of those adaptations which need to be investigated.

Parallel evolution signifies adaptation

As early as 1922, Annandale and I commented on a remarkable case of parallel evolution in the fish and tadpoles of mountain torrents by referring to the development of a suctorial disc in the fishes of the genus *Garra* Hamilton and tadpoles of *Rana afghana*

Günther. Annandale (1924*a*) again referred to it and, on the basis of my work on *Garra*,' pointed out that the different forms found in different types of environment correspond very closely with different stages in the post-larval development of the most highly specialized species. He then predicted that though 'our knowledge of the tadpoles is less complete, the analogy between them and the fish is so close that it is impossible to avoid the conclusion that a similar (but of course not an identical) line of evolution has been followed'. Annandale's prediction came true when I (1932) studied the development and probable evolution of the suctorial disc in the tadpoles of *Rana afghana* Günther. Similarly, in the case of Homalopteroid fishes, I (1932*a*) predicted that forms intermediate between *Vanmanenia* Hora and *Formosania* Oshima still remain to be discovered, and so it was no surprise when Fang described *Praeformosania*. The entire classification of the Homalopteroid fishes is based on adaptive characters and when discoveries of future taxonomic units can be predicted, it seems reasonable to believe that there is some directiveness in evolution.

Taxonomy and adaptations

In 1949, I discussed how a taxonomist assesses a species and how the value of characters may change with individual workers or when more material becomes available. I shall extend this point by referring to the changes that have taken place in recent years in the classification of the Homalopterid fishes, in which even the minutest characters used for taxonomic purposes can be shown to have some adaptive significance.

In 1920, I published a revision of the Indian Homalopteridae and Day's *Homaloptera* was divided into three genera. In 1932, after examining considerable material in European museums, I found that this very characteristic family is polyphyletic and showed on the basis of morphological characters that, whereas *Homaloptera* and its allied forms were derived from the Cyprinidae, *Gastromyzon* and its allied forms have been derived from the Cobitidae. In 1949, I had an opportunity to examine the material of these fishes in the American museums. As a result, the previous view was confirmed and the old Homalopteridae was definitely divided into two families, the Homalopteridae and the Gastromyzonidae (Hora, 1950). Though the material available for study of these fishes is very limited, we have studied them from several aspects, such as cranial osteology (Ramaswami, 1952), structure of scales (Law, 1950), and systematics and zoogeography (Silas, 1952). These studies have shown that the Gastromyzonidae comprise two definite stocks independently evolved from the Cobitidae, the Crossostominae and the Gastromyzoninae. Further, both the Gastromyzoninae and the Crossostominae are independently evolved on the mainland of Asia and in the island of Borneo (Hora, 1952*a*). In each group and in each geographical area, there are several lines of independent evolution showing thereby that the over-riding influence of swift currents has moulded several Cobitid forms independently and have made them converge so as to look superficially alike. For lack of enough material, our investigations into the so-called Homalopteridae of the older writers are not complete though I have been studying this family of fishes for over a generation now. True enough, Darwin enunciated his theory of the *Origin of Species* on the basis of accumulation of a great deal of data, but such encyclopaedic knowledge is perhaps not possible in these days. Now is the age of intensive studies, not of a single order or family but sometimes of a genus from all aspects. Though on account of the time factor, it may not be possible to demonstrate experimentally the rôle of adaptations in speciation, one will have to turn to the specialists of genera and species to build the edifice of the science of Organic Evolution.

Evolution: divergent and convergent

Both Annandale and I have been greatly impressed by the fact that evolution does not follow a straight course. One notices at every step that to meet the requirements of the environment sometimes the characters converge and sometimes they

diverge, but always with the ultimate aim of achieving the same object. In the study of the Homalopterid fishes or the fishes of the Glyptosternoid group of the family Sisoridae, one comes across divergent and convergent evolution in regard to every taxonomic character (Hora & Silas, 1952). The sum total of all the characters constitutes the organism which shows a remarkable adaptation to the environment, whatever may be the line of evolution of each character. The evolution of each character is determined by the initial stage at which it starts so that it acts as mere clay under the pressure of its environment, which moulds it and remoulds it so as to keep it fully adjusted to the requirements of the external condition of its existence.

How do new characters arise

Annandale (1924*a*) thus summarized his views on evolution:

> 'Mendelism is true in some cases; some species produce mutations, but gradual changes also take place under the influence of environment, and are perpetuated. In some circumstances these changes are utilized and become more strongly developed, in some they produce harmless by-products; in others the result is harmful and the race perishes. No one formula can express, much less explain, evolution.'

Since Annandale's time we have observed many more facts concerning adaptations; we are accordingly in a position to take a much bolder stand in evaluating their importance in evolution. Whatever may be the source of variations, Lamarckism, Mendelism, Darwinism, Weismannism, or any other, each variation is subjected to the test of its fitness to the environment: if it passes that test it survives, otherwise it is wiped out. The most predominant factor in evolution is adaptation and Dr. Cain is, thereby, perfectly justified in cautioning students of evolution 'that those characters or variation patterns that have been described as non-adaptive or random should properly be described as "uninvestigated". One must not assume randomness (or selection) without proof'.

In the evolution and distribution of the hill-stream fishes of south-east Asia, we have now found that the orogenic movements that gave birth to the Himalayas had a great rôle to play. The movements affected the neighbouring countries and produced many resultant mountain ranges. The streams in the Himalayas and the associated mountain ranges became rejuvenated with each upheaval, thus providing a very favourable stimulus for the production of more and more specialized adaptive fishes. As the peninsular region remained more or less stable during these orogenic movements, we did not understand the evolution of new genera of fishes in the Western Ghats having affinities with those found in the Assam Hills, Eastern Himalayas and further east. Now we know that this was made possible by the tilting of the Peninsula by which the Western Ghats was uplifted and the streams in it were rejuvenated (Menon, 1951), thus providing a direct cause for the production of genera like *Bharania* Hora and *Travancoria* Hora. Hence it will be seen that we require to supplement our biological studies with a knowledge of the palaeogeography of India before we can hope to understand the problems of evolution and distribution of our torrent-inhabiting fishes.

Principles of evolution

In the above account of various aspects of adaptations and their bearing on organic evolution, I have relied mainly on observations I have made myself or of which I have personal knowledge. I am, therefore, in the fortunate position of being able to substantiate each observation with more detailed information. It will be seen that the following biological principles can be enunciated for a proper understanding of evolutionary changes in nature:

1. New characters, as a rule, arise as modifications of some pre-existing structures. There is no such thing as the evolution of entirely new

characters. Thus there is always an organic link between the past and the present.

2. The evolution of characters is governed by the innate tendencies of heredity, as well as by the external environmental influences. In fact, both Nature and Nurture play a significant part in the make-up of an individual.
3. New variations or characters, by whatever means they may arise, are tested for their adaptiveness to the external conditions of the existence of the organism concerned. The non-adaptive characters, if harmful to the existence of the organism, disappear or the race perishes. In the end, only adaptive characters persist and form the basis of future evolutionary changes. It must be remembered that evolution is of the animal through the production of purposeful characters, and not of the characters without any relation to the life of the animal.
4. Evolutionary changes are thus directed towards achieving certain definite objectives. Evolution takes tortuous paths for the attainments of its objectives, for it goes on moulding and remoulding pre-existing characters to fit them to the needs of environment. This view is amply justified by marked divergences and convergences one comes across in Nature. The same objective can be gained by similar organisms by applying different means or conversely by different animals by resorting to similar modifications.
5. Fluctuations in environmental conditions, whether of the gene-complex or of the animal as a whole, are the main sources of variations and thereby of the production of new characters. In the case of the hill-stream fish-fauna of south-east Asia, the production of new families, genera and species can be correlated with the orogenic movements due to the birth of the Himalayas or other similar violent earth movements. So long as the environment remains static, the organisms do not change very much, but any dynamic environment, such as torrents, marshes, estuaries, shore-line, etc., is an open book for the study of evolution. Palaeogeographical changes have very often converted a static environment into a dynamic one and it is during such periods of the earth's history that vast evolutionary changes have been observed.

Conclusion

I believe I have made it sufficiently clear that the study of evolution is in the main a study of adaptations. Adaptations resolve themselves into two main lines of investigation: the study of the characters of the animals and the study of the environment in which the animal lives. The study of characters has advanced to a very high pitch of efficiency, for we are now studying the minute parts of chromosomes and interpreting them in terms of heredity. We are, on the other hand, still very ignorant of environment. This deficiency is mainly responsible for our quarrels about the theories of evolution and for the inadequate understanding of man and his needs. The future lies in ecological studies, whether of organisms or of man. So long as we remain ignorant of environmental gradations, it is better to follow Dr. Cain's advice and treat apparently non-adaptive character as 'uninvestigated'. This attitude of mind will at least enable the younger generation to investigate nature more thoroughly, and thereby, to cull from it the secrets of evolutionary changes.

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ON A MODIFIED DEFINITION OF RIESZ POTENTIAL AND ITS CORRESPONDENCE TO THE WENTZEL POTENTIAL.

By L. S. KOTHARI *and* P. L. BHATNAGAR, *F.N.I.*,
University of Delhi.

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In a recent paper Auluck and Kothari (Jr.) (1951) (later referred to as A-K. 1) have given, in the framework of the classical electro-magnetic theory, a modified definition of the Riesz potential. The usual definition of the Riesz potential (Fremberg (1946)) gives, on analytic continuation to $\alpha = 0$, the Maxwell potential, whereas the modified definition of the Riesz potential gives the Wentzel potential, and hence appears to be more suitable in quantum electrodynamics. The object of the present paper is to discuss explicitly this correspondence between the modified Riesz potential and the Wentzel potential.

We define the metric tensor $g_{\mu\nu}$ as

$$g_{00} = 1 \; ; \; g_{11} = g_{22} = g_{33} = -1 \; ; \; g_{\mu\nu} = 0 \text{ for } \mu \neq \nu,$$

and take the velocity of light as unity. Following Dirac (1947) the scalar product of two four-vectors A_μ, B_μ (the Greek suffixes take the values 0, 1, 2, 3 and the Latin suffixes the values 1, 2, 3) is denoted by

$$[A, B] = A_\mu B^\mu = A_0B_0 - A_1B_1 - A_2B_2 - A_3B_3 = A_0B_0 - (AB)$$

where (AB) is the scalar product of the space parts of A_μ and B_μ. The length (positive) of the space part of a vector A_μ is written as $|A|$.

The modified Riesz potential (A-K. 1) is defined at a space-time point x by the following equation (which represents a Fourier expansion)

$$A^\alpha_\mu(x) = H(\alpha) \int_D k^{\alpha-2} \{A_{k\mu} e^{i[k,x]} + \dot{A}_{k\mu} e^{-i[k,x]}\} \, d^4k, \quad \ldots \quad \ldots \quad (1)$$

where

$$A_{k\mu} = \frac{1}{4\pi^2 i} \int_S j_\mu(z') e^{-i[k,z']} d^4z', \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

and

$$H(\alpha) = \frac{2}{\Gamma(\alpha/2)\Gamma(1-\alpha/2)} = \frac{2}{\pi} \sin \frac{\pi\alpha}{2}. \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

D is the four-dimensional domain bounded by the light-cone $k_0 > 0$, $[k,k] = 0$, $j_\mu(z')$ in (2) is the current-density four-vector and the integral in (2) is over the whole of space-time. The parameter α is arbitrary: The integral in (1) converges for $\alpha < 0$.

We first calculate the potential at any point x, due to a general charge-distribution. Substituting (2) in (1), we have

$$A^\alpha_\mu(x) = \frac{H(\alpha)}{4\pi^2 i} \int_D \int_S k^{\alpha-2} j_\mu(z') \{e^{i[k, x-z']} - e^{-i[k, x-z']}\} d^4k d^4z'. \quad \ldots \quad (4)$$

To evaluate this we consider a typical integral

$$I^{\alpha} = \frac{H(\alpha)}{4\pi^2 i} \int_D k^{\alpha-2} e^{i(k,x)} d^4k. \qquad \ldots \quad \ldots \quad \ldots \quad (5)$$

Transforming the integration variables from k_0, k_1, k_2, k_3 to k, K_1, K_2, K_3, where

$$k^2 = k_0^2 + K^2 \text{ and } k_i = K_i,$$

and hence

$$d^4k = \frac{k\,dk}{\sqrt{k^2+K^2}}\, d^3K,$$

we have

$$I^{\alpha} = \frac{H(\alpha)}{4\pi^2 i} \int_k \int_{K_i} k^{\alpha-1} e^{ix_0\sqrt{k^2+K^2} - i(Kx)} \frac{dk\, d^3K}{\sqrt{k^2+K^2}}.$$

To analytically continue this to $\alpha = 0$, we may make use of the Riemann-Liouville integral

$$\operatorname*{Lt}_{\alpha\to 0} \alpha \int x^{\alpha-1} f(x)\, dx = f(0) \qquad \ldots \quad \ldots \quad \ldots \quad (6)$$

so that

$$I^0 = \frac{1}{4\pi^2 i} \int_{K_i} e^{ix_0|K| - i(Kx)} \frac{d^3K}{|K|}.$$

Transforming the above integral into polar co-ordinates $|K|$, θ, ϕ, and integrating over ϕ, we get

$$\begin{aligned} I^0 &= \frac{1}{2\pi i} \int_{|K|=0}^{\infty} \int_{\theta=0}^{\pi} e^{ix_0|K| - i|K||x|\cos\theta} |K|\, d|K| \sin\theta\, d\theta \\ &= \frac{1}{2\pi|x|} \int_{|K|=0}^{\infty} e^{ix_0|K|} \left\{ e^{-i|x||K|} - e^{i|x||K|} \right\} d|K| \\ &= \frac{1}{2|x|} \left\{ \delta(x_0-|x|) - \delta(x_0+|x|) \right\} \end{aligned}$$

or $$I^0 = \tfrac{1}{2}\Delta(x), \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

where

$$\Delta(x) = \frac{1}{|x|} \left\{ \delta(x_0-|x|) - \delta(x_0+|x|) \right\} \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (8)$$

is the Heisenberg delta function.

In view of (7), (4) reduces to

$$A_{\mu}^{0}(x) = A_{\mu}(x) = \int_S \frac{j_{\mu}(z')}{|x-z'|} \left[\delta\{(x_0-z_0')-|x-z'|\} - \delta\{(x_0-z_0')+|x-z'|\} \right] d^4z' \qquad (9)$$

For the case $x_0 > z_0'$, which is of physical importance, only the first delta function contributes and on integrating with respect to z_0', we get

$$A_{\mu}(x) = \iiint \frac{j_{\mu}(x_0-|x-z'|,\, z_i')}{|x-z'|}\, d^3z', \qquad \ldots \quad \ldots \quad \ldots \quad (10)$$

which is the classical retarded potential. It will be noted that for $x_0 < z_0'$, (9) yields the advanced potential.

If the current is generated by a single point-particle of charge e, we have

$$j_\mu(z') = ev_\mu \delta^4(z-z')$$

where z is the space-time co-ordinate of the particle. In this case (2) reduces to

$$A_{k\mu} = \frac{e}{4\pi^2 i}\int_{-\infty}^{\tau_0} v_\mu e^{-i[k,\,z]}\,d\tau, \qquad \ldots\ \ldots\ \ldots \quad (11)$$

τ being the proper time of the particle, and v_μ its velocity at the point z corresponding to the proper time τ. Making use of (11) we can write (1) as

$$A_\mu^\alpha(x) = \frac{H(\alpha)e}{4\pi^2 i}\int_{-\infty}^{\tau_0} v_\mu d\tau \int_D k^{\alpha-2}\left\{e^{i[k,\,x-z]} - e^{-i[k,\,x-z]}\right\} d^4z,$$

which, when integrated over k in the same manner as shown above for the case of a general charge distribution, reduces to

$$A_\mu(x) = e\int_{-\infty}^{\tau_0} v_\mu(z)\,\Delta(x-z)\,d\tau. \qquad \ldots\ \ldots\ \ldots \quad (12)$$

It can easily be seen that (11) is a solution of the equations

$$\frac{\partial^2}{\partial x_\mu\,\partial x^\mu}\cdot A_\nu(x) = 0 \qquad \ldots\ \ldots\ \ldots\ \ldots \quad (13a)$$

and

$$\frac{\partial A_\mu(x)}{\partial x_\mu} = -e\Delta(x-z) \qquad \ldots\ \ldots\ \ldots\ \ldots \quad (13b)$$

which define the Wentzel potentials. This shows that the modified definition of the Riesz potential, when analytically continued to $\alpha = 0$, leads to the Wentzel potential.

We shall now consider (12) in a little more detail. If the point x lies inside the future part of the light cone of z at the proper time τ, i.e. if

$$[x-z,\,x-z] > 0, \quad x_0 - z_0 > 0 \qquad \ldots\ \ldots\ \ldots \quad (14)$$

then for this case, since the Δ-function vanishes over the entire range of integration, $A_\mu(x) = 0$. In the case of the point x lying outside the light cone of z, i.e.

for $$[x-z,\,x-z] < 0 \qquad \ldots\ \ldots\ \ldots\ \ldots \quad (15)$$

there is just one point of τ, the retarded proper time for the field point x, where Δ-function does not vanish. Therefore, in this domain, on integration, one obtains

$$A_\mu(x) = e\left|\frac{v_\mu}{[v,\,x-z]}\right|_{\text{ret.}} \qquad \ldots\ \ldots\ \ldots\ \ldots \quad (16)$$

where 'ret' denotes that the value of the function is to be taken at the retarded proper time. This is the classical Lienard-Wiechert potential.

If the point x lies inside the past part of the light cone of z, i.e. if

$$[x-z,\,x-z] > 0, \quad x_0 - z_0 < 0, \qquad \ldots\ \ldots\ \ldots\ \ldots \quad (17)$$

there are two values of τ for which the Δ-function does not vanish. One corresponds to the retarded proper time of and another to the advanced proper time

of x. The contribution to the potential from the retarded proper time is the same as (16), while it can easily be proved that the contribution from the advanced proper time is

$$-e\left|\frac{v_\mu}{[v, x-z]}\right|_{\text{adv.}}$$

where 'adv' denotes that the value of the function is to be taken at the advanced proper time. Thus for the domain defined by (17)

$$A_\mu(x) = e\left|\frac{v_\mu}{[v, x-z]}\right|_{\text{ret}} - e\left|\frac{v_\mu}{[v, x-z]}\right|_{\text{adv.}} \quad .. \quad .. \quad .. \quad .. \quad (18)$$

Summing up our results we have

$$\left.\begin{aligned} A_\mu(x) &= 0 && \text{when (14) holds} \\ &= e\left|\frac{v_\mu}{[v, x-z]}\right|_{\text{ret.}} && \text{when (15) holds} \\ &= e\left|\frac{v_\mu}{[v, x-z]}\right|_{\text{ret.}} - e\left|\frac{v_\mu}{[v, x-z]}\right|_{\text{adv.}} && \text{when (17) holds} \end{aligned}\right\} \quad .. \quad .. \quad (19)$$

The potential on the world line of the electron will be given by

$$A_\mu^{\text{world line}} = \frac{e}{2}\left\{\left|\frac{v_\mu}{[v, x-z]}\right|_{\text{ret.}} - \left|\frac{v_\mu}{[v, x-z]}\right|_{\text{adv.}}\right\}, \quad .. \quad .. \quad (20)$$

when we take the limit $x-z \to 0$. It can be shown that in the limit (20) reduces to

$$A_\mu^{\text{world line}} = e\dot{v}_\mu. \quad .. \quad .. \quad .. \quad .. \quad (21)$$

This result can also be derived using Fremberg's definition for the Riesz potential.

The field tensor can be deduced from (19) by differentiation

$$F_{\mu\nu} = \frac{\partial A_\nu}{\partial x_\mu} - \frac{\partial A_\mu}{\partial x_\nu}. \quad .. \quad .. \quad .. \quad .. \quad (22)$$

The derivatives have to be taken with respect to the field point x_μ, but the quantities occurring in (19) are the functions of the co-ordinates corresponding to either the retarded or the advanced proper time. Advanced or the retarded proper times are defined by the relation

$$[x-z, x-z] = 0,$$

and from this it follows that

$$\frac{\partial \tau}{\partial x_\mu} = \frac{x_\mu - z_\mu}{[v, x-z]}. \quad .. \quad .. \quad .. \quad .. \quad (23)$$

Using this relation we have

$$\left.\begin{aligned} F_{\mu\nu} &= 0 && \text{when (14) holds} \\ &= |F_{\mu\nu}|_{\text{ret.}} && \text{when (15) holds} \\ &= |F_{\mu\nu}|_{\text{ret.}} - |F_{\mu\nu}|_{\text{adv.}} && \text{when (17) holds} \end{aligned}\right\}, \quad .. \quad (24)$$

$$|F_{\mu\nu}|^{\text{ret.}}_{\text{adv.}} = e\left|\frac{(x_\mu-z_\mu)v_\nu-(x_\nu-z_\nu)v_\mu}{[v,x-z]^3}(1-[\dot{v},x-z])\right.$$
$$\left.+\frac{(x_\mu-z_\mu)\dot{v}_\nu-(x_\nu-z_\nu)\dot{v}_\mu}{[v,x-z]^2}\right|^{\text{ret.}}_{\text{adv.}} \quad .. \quad (25)$$

The field on the world line of the electron is, therefore, given by the usual expression:

$$F_{\mu\nu}^{\text{world line}} = \tfrac{1}{2}\{|F_{\mu\nu}|_{\text{ret.}}-|F_{\mu\nu}|_{\text{adv.}}\}$$
$$= \tfrac{2}{3}e(\ddot{v}_\mu v_\nu-\ddot{v}_\nu v_\mu). \quad .. \quad .. \quad .. \quad .. \quad (25)$$

Summary

It is known that the usual definition of the Riesz potential gives an analytic continuation to $\alpha = 0$, the Maxwell potential, whereas the modified definition given by Auluck and Kothari gives the Wentzel potential. In this paper the correspondence between the modified Riesz potential and the Wentzel potential is explicitly worked out.

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BAND SPECTRUM OF CARBON-DISULPHIDE, PART II.

By C. RAMASASTRY, *I.C.I. Research Fellow, N.I.S.I., Department of Applied Physics, Andhra University, Waltair.*

(Communicated by Dr. K. R. Rao, F.N.I.)

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1. GENERAL SURVEY

In part I of this series, Ramasastry and K. R. Rao (1947) * reported the results of their investigations on the absorption spectrum of carbon-disulphide in the 2000A. region. The bands were ascribed to an allowed electronic transition and the long main progression of intense bands first reported by Price and Simpson (1938) involving the totally symmetrical vibration of the upper state having a frequency of 410 cm.$^{-1}$ was confirmed. From a second similar progression, newly observed, the energy of the bending or the deformation vibration of the excited electronic state was estimated to be about 235 cm.$^{-1}$, on the basis of Herzberg and Teller's selection rules for an allowed transition between two electronic states in both of which the molecule is linear. The intensities of the bands within each progression and between the two progressions, considered in relation to the Franck-Condon principle, indicate that the bond distance is considerably increased due to the electronic excitation while the bond angle has not altered sensibly from 180°.

In this part, it is proposed to give the details of an investigation on the near ultraviolet absorption of CS_2 vapour in the region 3800A.–2900A. Wilson (1929) published a comprehensive catalogue of the wavelength data of about 670 absorption peaks in this region. The work of Wilson (1929), Jenkins (1929), and Watson and Parker (1931) was, however, done when not much was known even about the ground electronic state of the molecule. A fairly complete knowledge of this state is available at the present day. The molecule is linear in the ground state, the two non-degenerate vibrations, one of which is totally symmetrical and the other anti-symmetrical, are known to have energies of about $\nu_1'' = 656{\cdot}5$ cm.$^{-1}$ (in liquid) and $\nu_3'' = 1523$ cm.$^{-1}$ (in gas) and the third which is the doubly degenerate bending vibration has the frequency $\nu_2'' = 396{\cdot}7$ cm.$^{-1}$ (in gas). Later, Liebermann (1941) analysed the rotational structure of six bands in this region. He mentioned that Herzberg also attempted an analysis of the bands (unpublished work). Mulliken (1935, 1937, 1941, 1942) in a series of articles developed the view that the upper state of the near ultraviolet band system of CS_2 is probably $^1\Pi_g$ if the molecule remained linear; the forbidden electronic transition between this and the $^1\Sigma_g^+$ ground electronic level being, however, made allowed by vibronic selection rules (due to the excitation of non-totally symmetrical vibrations). The observed low intensity of absorption in this region compared to that in the λ 2000 region points to such a possibility. More recently, supported by the work of Liebermann (1941), Mulliken (1941) confidently asserts that the molecule is bent in the equilibrium configuration of the upper electronic state in which case the $^1\Pi_g$ (of the linear molecule) level would split into $^1A_2$ and $^1B_2$ electronic states (appropriate for a bent molecule). This would make

* See this for earlier references.

extensive series in ν_1' and ν_2' possible which can probably explain the perplexingly large number of the bands observed.

2. Approach to the Problem

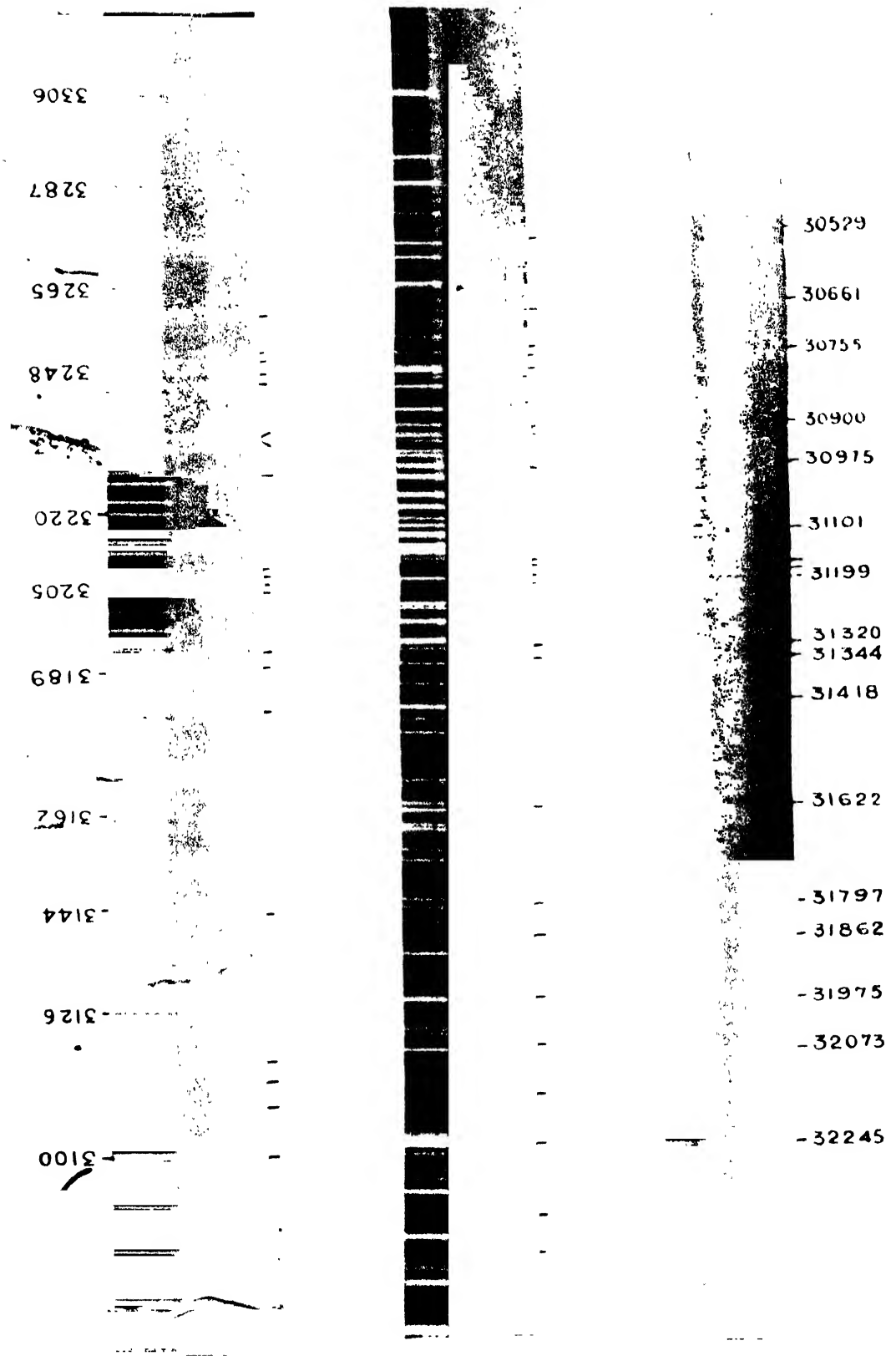
As a part of the general programme of work in the spectroscopy laboratory of the Andhra University, the author considered it desirable to investigate the 3300A. system of CS_2 molecule in the light of the excellent work on the XY_2 type triatomic molecules initiated by Mulliken at the Ryerson Physical Laboratory (on the 30,000 lines/inch 30 ft., 5½ in. ruled surface Chicago grating) and in view of the recent developments in the interpretation of the vibrational structure of the near ultraviolet spectra of polyatomic molecules, particularly benzene and its derivatives. As the number of absorption bands of CS_2 recorded by Wilson between 3800A. and 2900A. is very large, it is considered necessary to find out in the first instance to what conditions of the absorbing gas do the various measurements correspond. As it is well known that the absorption bands grow more intense and broader with increase in the number of molecules of the gas encountered in the absorbing path and the temperature of the gas, and also because it is known from the work of Jenkins (1929), Kush and Loomis (1939), and Liebermann (1941) that the structure of each band extends in certain cases to as much as 17 to 20 wave-number units, it is expected that a study in the proposed direction should make it possible to associate some of the bands measured by Wilson with the rotational detail of the more prominent ones. If this is done, there may be only a comparatively smaller number of bands that are to be accounted by vibrations. The most intense portion of a band can also be accurately located for use in the vibrational analysis. This has necessitated a close study of the development of the bands right from the condition when they made their first appearance to that when they are obliterated by continuous absorption due to the intensification, broadening and consequent overlapping by neighbouring bands.

Also, as has been pointed out by Wilson (1929) qualitatively and Mulliken (1941) from theoretical considerations, the apparent complexity of the spectrum may be due to the presence of more than one overlapping system. In such a case, it can be argued that because the positions and intensities of all such systems will not in general be exactly equal, it might be possible to isolate at least the intense bands belonging to the most intense of these systems by reducing the number of molecules in the absorbing path to such an extent that bands of the other less intense systems, if any, become either extremely weak or do not appear. If the expected simplification of the spectrum occurs, it would also be easier to attempt a vibrational analysis of the bands. In planning these experiments, the author had in mind the absorption spectra of the near ultraviolet band systems of substituted benzenes.

3. Experimental

So it is sought to reduce the number of molecules in the absorbing gas until the number of bands recorded is the minimum. Such a condition is shown in Plate V(*a*) from which about a dozen prominent bands alone could be measured. The absorbing column is 2·5 cm. long and the side tube containing the CS_2 liquid is kept surrounded by ice + salt mixture at −15°C. The experimental set-up is similar to that employed in the earlier investigation on CS_2. Plate V(*b*) represents the spectrum taken with a 3-cm. all-quartz absorption cell at a temperature of 27°C., pressure is not known. The condition just marks a slight intensification of the absorption over that in Plate V(*a*).

Ilford Special rapid plates were used to photograph the bands. Exposure time ranged from two minutes on the Hilger Medium Quartz to one hour on the Hilger Quartz Littrow with the source of continuum a 12-volt 25-watt tungsten filament lamp with a special sucked-in thin pyrex window, supplied by the General Electric Company.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31862
31975
32073
32245

4. Analysis

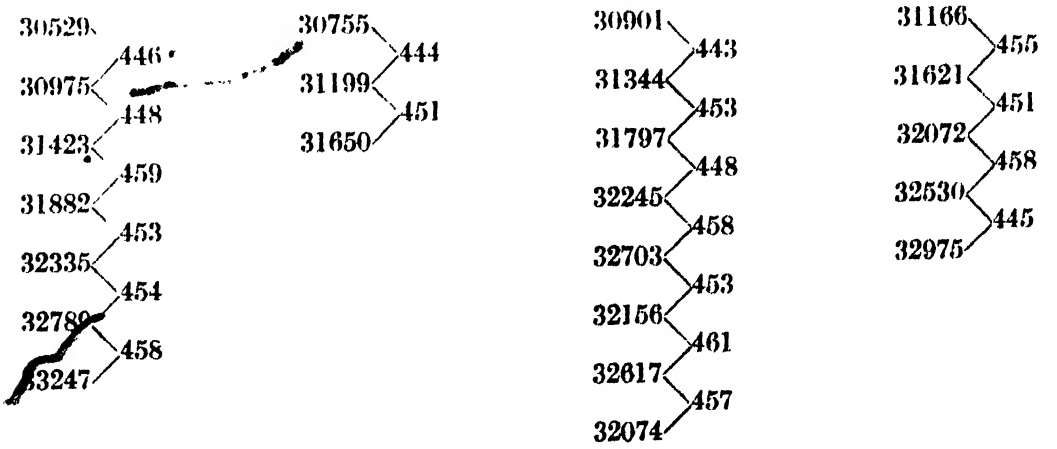
In this section, some regularities observed in the absorption spectrum of CS_2 vapour, in the region λ 3450-λ 2900 will be presented. Though they have not led to the complete vibrational analysis of the entire band spectrum from λ 3800 to λ 2900, it is considered that the regularities noticed are of significance and may as well form the starting point for the analysis.

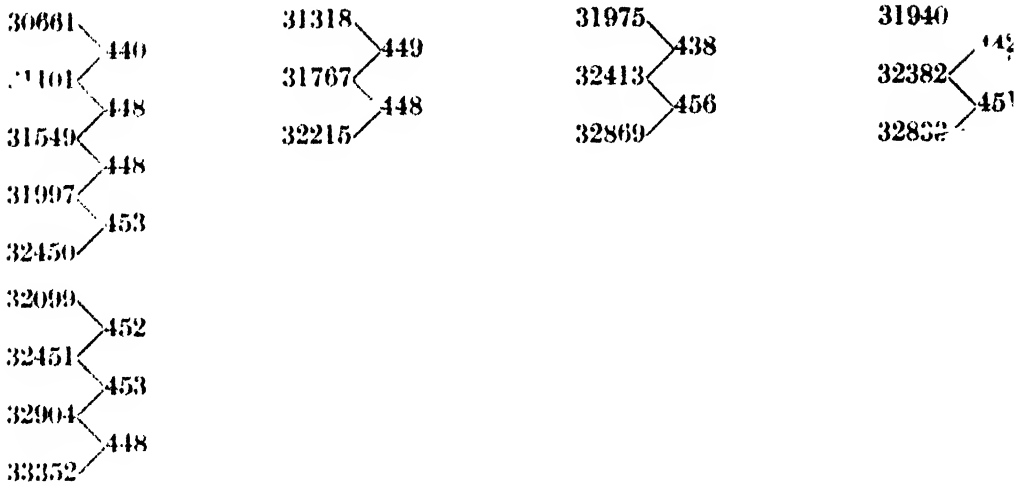
To begin with, bands observed in Plate V(*a*) alone are considered. No two prominent bands differed by any of the ground state vibrational frequencies of ν_1'' 656, ν_2'' 397 and ν_3'' 1523 cm.$^{-1}$. However, 31199—30529 670, 31183—30529=654 and 31975—31318=657 were noted, of which the last one only is consistent with the relative intensities of the two bands concerned. The picture did not also reveal any unmistakable progressions.

A search has also been made among these bands for an interval of about 270 cm.$^{-1}$, long and prominent progressions of which were noticed by the earlier investigators in the long wavelength region between 3750A. and 3425A. This was also not successful. The author's findings on these long wavelength progressions are reserved for publication in a subsequent communication. Suffice it here to say that these 270 cm.$^{-1}$ progressions started in the 3700A. region and tend to progress towards shorter wavelengths. The interpretation of 270 cm.$^{-1}$ as an upper state vibrational frequency necessitates the location of the origin of the band system at the long wavelength end of the spectrum. The absence of this interval in the $\lambda\lambda$ 3300–2900 region shows that there are two different band systems involved, one in the long wavelength region and the other in the short wavelength region. It should be noted in this connection that in Plate V(*a*) there are no bands recorded on the red side of λ 3274·6, ν30529 and only a few isolated bands developed at moderately higher absorption paths. Between 3450A. and 3350A. the region of maximum overlap between the two band systems, one can expect some bands of the short wavelength system which arise from the vibrating ground state of the molecule. It has thus become possible to some extent to isolate the bands belonging to the short wavelength system which is found to be more intense than the long wavelength system. Experimentally it appears justified to consider most of the bands in the reproductions, Plate V, as belonging to a single system.

From the absorption pictures obtained at moderately higher pressures and longer path lengths, particularly the Medium Quartz spectrogram shown in Plate VI, it has become possible to find a few progressions of bands involving an interval of about 450 cm.$^{-1}$. These are indicated below.

Progressions





Most of the intense bands in the region 3300A. 2950A. could be included in the above progressions. It should be mentioned here that Wilson (1929) also observed the differences 31344—30900 444, 31198—30755 443 and 31182—30738 444.

The irregularities in the above-mentioned 450 cm.$^{-1}$ progressions are within the errors of measurement, as even in the most favourable cases the different measurements differed by about two wave numbers. This is due to the nature of the bands. Where sharp heads are found these are measured, while in most other cases the centres are measured. Jenkins (1929) pointed out that most of the bands are of simple *P-R* branch type and it is the positions of the intensity minima rather than the maxima that are to be used in forming the progressions; the former correspond to the so-called missing lines while the positions of the latter are liable to fluctuations with changes in the absorbing path of the gas. The location of the minima is no doubt possible in the case of certain bands even under the comparatively lower dispersion employed in the present investigation. As it could not, however, be done in the case of most other bands, the above-mentioned method of measurement is adopted. If higher dispersion is employed in this region of the absorption spectrum, it could be expected to systematise the intervals in the above progressions and indicate sudden jumps, if any. In forming the above progressions the qualitative appearance of the individual bands is kept in mind to be of guidance in the interpretation of the vibrational structure. The reality of the progressions cannot be doubted and an average value of 450 cm.$^{-1}$ is adopted as the characteristic interval of these progressions.

From its magnitude this 450 cm.$^{-1}$ has to be considered as a vibrational frequency of the *upper* electronic state. There are two possibilities for its interpretation: (1) as the C-S bending vibration ν_2' (ground state value 397 cm.$^{-1}$); (2) as the C-S stretching valence vibration ν_1' (ground state value 656 cm.$^{-1}$). The first of these accepts an increase in the vibrational frequency due to the excitation of the electron. The observed violet degradation of some of the bands also indicates that the moment of inertia has decreased in the upper state. If the molecule retained its linearity, this would mean a decrease in the internuclear distance presumably due to an increase in the bond energies which would result in an increase of the vibrational frequencies. However, in the case of the polyatomic molecules the vibrational frequencies generally decrease with the electronic excitation, though the possibility of increase cannot be altogether ruled out. For a molecule linear in both the electronic states, Herzberg and Teller's selection rules do not permit the appearance of ν_2 progressions which require the corresponding quantum number to change progressively by 0, 1, 2, 3, etc. The same arguments of the appearance of lengthy progressions advanced by Mulliken (1941) against the interpretation of 270 cm.$^{-1}$ (observed

among the long wavelength bands) as due to $2\nu_2'$ of a linear molecule are also applicable here. Moreover, the molecular orbital considerations of Mulliken led him to consider that there should be a decrease in the vibrational frequencies due to the excitation of the electron. At the same time the decrease should not be considerable as only one electron has jumped while eight bonding electrons remain.

This brings us to the other possibility of regarding the 450 cm.$^{-1}$ frequency as representing the totally symmetrical C-S bond stretching (breathing) valence vibration of the upper state. There is the expected fall in frequency from 656 to 450 as the molecule goes from the ground to the excited electronic state. The selection rules are not against its appearance. In such an event, the decrease of at least one of the moments of inertia required to explain the observed violet degradation of the bands is probably due to a slight bending of the molecule in the upper state.

In what follows, a discussion will be presented regarding the various possibilities of the upper state. As for the ground state, the molecule carbon-disulphide is homologous to carbon-dioxide. Both have zero dipole moments. The infra-red and Raman activity of the fundamental vibrations indicates that CS_2 like CO_2 is linear and symmetrical and has the symmetry $D_{\infty h}$. The lowest vibronic state, which is totally symmetrical can be represented by $^1\Sigma_g^+$ following the nomenclature recommended by Mulliken from an analogy of the diatomic molecules.

Case i.—Linear symmetrical upper state; allowed electronic transition ; internuclear distance not altered. One may expect strong 0–0 band associated with a number of weaker bands due to 1–1 transitions of both the totally symmetrical and non-totally symmetrical vibrations. The appearance should *somewhat* correspond to the $\Delta v = 0$ sequence of a normally developed band system of a diatomic molecule. Bands with $\Delta v_1 = 1, 2, 3$, etc. will be weak while those with $\Delta v_1 = -1, -2, -3$, etc. will be weaker. Weak transitions with $\Delta v = 2, 4$, etc. and weaker (due to the effect of Boltzman factors in absorption work) transitions with $\Delta v = -2, -4$, etc., of the non-totally symmetrical vibrations (ν_2 and ν_3) can also be expected. All these will be displaced from the 0–0 band by values equal to the appropriate multiples of the corresponding vibrational frequencies. Associated with each of the bands which arise from change in the quantum number of either of the non-totally symmetrical vibrations there can be present bands due to the 1–1 transitions of the totally symmetrical vibration, giving the appearance somewhat akin to the $\Delta v = 1, 2, 3, -1, -2, -3$, etc. sequences of the diatomic case.

Such features are, however, very rarely met with in the absorption spectra of polyatomic molecules, but when observed are to be ascribed to the excitation of an electron from one non-bonding orbital to another or between two equally bonding orbitals. Then it follows that the vibrational frequencies in the two electronic states differ only slightly and such a transition can generally be expected in the vacuum ultraviolet.

In the near ultraviolet asborption spectrum of CS_2, the band at λ 3204·3, ν 31199 conforms to the above description. It is a clearly violet degraded band with a sharp *P*-head. Three or four weaker but equally sharp bands developed on its long wavelength side at longer effective paths, their intensity decreasing with their distance from the main band.

31198·3 (16·5) 31181·8 (16·3) 31165·5 (15·2) 31150·3 (17·3) 31133.

The mean interval between these bands is about 16 cm.$^{-1}$. If, as stated above, these form the so-called $\Delta v_1 = 0$ sequence, one has to explain their positions as due to a decrease by 16 cm.$^{-1}$ of the frequency of the totally symmetrical breathing vibration from its value of 656 cm.$^{-1}$ in the ground state as the molecule gets into the upper electronic level. ν_1' will then have a value of about 656—16 = 640 cm.$^{-1}$. But this interval does not recur among the other bands. In this case the expected picture of the band system is extremely simple and cannot explain the large number of bands actually present.

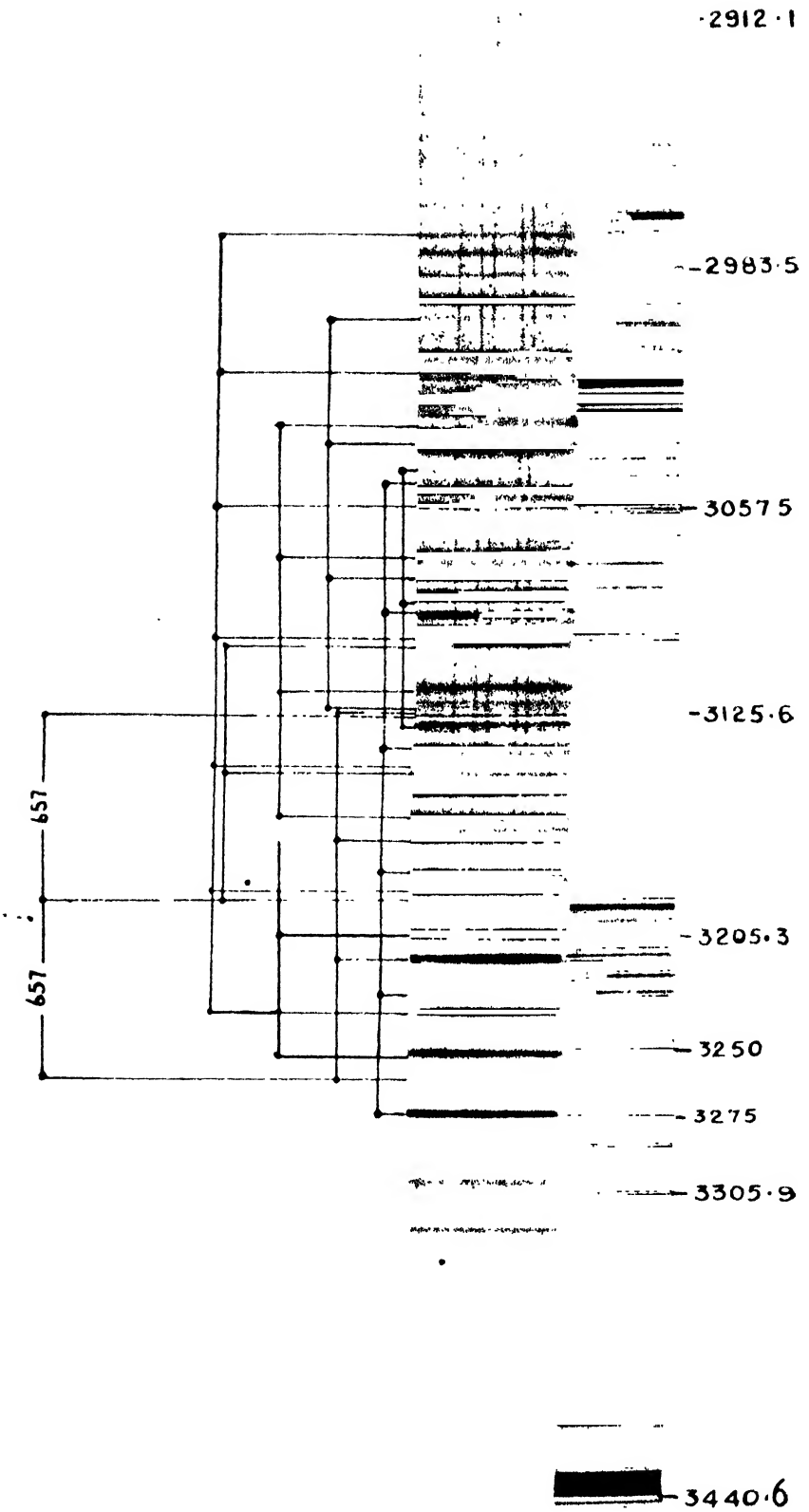
The possibility of regarding this 16 cm.$^{-1}$ as $\Delta\nu_2$ will be considered in the next section.

Case ii.—The molecule is linear symmetrical in its upper state and the electronic transition is an allowed one. Also the internuclear distances in the two electronic states differ only moderately (slightly less or slightly more for the stationary positions of the nuclei). In this case the 0–0 is generally very strong though not the strongest. But the excitation of the totally symmetrical vibration of the upper state by a few quanta (1, 2, 3, 4, etc.) can make the internuclear distance at the end positions of the oscillation approximately the same as in the vibrationless ground state—a condition according to the Franck-Condon principle most suitable for the electronic transition; the electron jump takes place and the molecule finds itself in a vibrating upper state. The corresponding band will be the strongest.

The expected prominent features of such an electronic transition would be the presence of long progressions of single frequency, the most intense of which will be $(v00)'$ $(000)''$. Next in order of intensity will be the progressions $(v20)'$–$(000)''$. The intensities of the progressions arising from the vibrationless ground state decrease in the order $(v00)'$ $(000)''$, $(v20)'$–$(000)''$, $(v40)'$–$(000)''$,....and $(v02)'$–$(000)''$, $(v04)'$ $(000)''$,....and other $\nu_2\nu_3$ combinations $(v22)'$–$(000)''$, etc. All the above represent allowed vibronic transitions for a molecule linear in both the electronic states and the electronic transition a permitted one. However, the F-C principle favours only the first of these while it is against the others in which either $\Delta\nu_2$ or $\Delta\nu_3$ or both are greater than zero. There are a further set of progressions allowed by the vibronic selection rules and favoured by the F-C principle. These are $(v00)'$—$(v00)''$, $(v10)'$—$(v10)''$, $(v20)'$—$(v20)''$,....$(v01)'$—$(v01)''$, $(v02)'$—$(v02)''$,.. .., and $(v11)'$—$(v11)''$, etc., all of which involve $\Delta\nu_2 = \Delta\nu_3 = 0$ and $\Delta\nu_1$ any value. But the Boltzmann factors are against these as they arise from vibrating lower state. The F-C principle is against one set and the Boltzmann factors against the other, the $(v00)'$ $(000)''$ is the only one which is favoured by both. An attempt has been made to fit in the observed bands of CS_2 into the above scheme of analysis but it proved futile. For instance, taking 30529 band as the first member, the intense bands do not form into regular progressions. (Compare the appearance of the 2000A. system.) From the description of the bands in the region $\nu 31139 - \nu 31133$ given under case (i), they may as well be due to $\Delta\nu_2 = \Delta\nu_3 = 0$. If they represent the 0–0, 1–1, 2–2, etc. transitions involving the deformation vibration, we have $\nu_2'' - \nu_2' = 16$ cm.$^{-1}$ or $\nu_2' = 381$ cm.$^{-1}$. The appearance of as many as four members on the red side with such intensity can be more easily explained from the point of view of both Boltzmann and statistical weight factors when the transitions involve the bending vibration which has the smallest frequency of the ground state $\nu_2'' = 397$ cm.$^{-1}$ rather than $\nu_1'' = 656$ cm.$^{-1}$ which was considered in case (i). A search for intervals of $2\nu_2' = 762$ cm.$^{-1}$ proved futile. Though the two prominent bands, 30529 and 30900–30909, differed by 371–380 cm.$^{-1}$, this frequency value of 380 cm.$^{-1}$ for the upper state deformation vibration could not explain the other intense bands in a consistent way.

Case iii.—Linear symmetrical upper state, allowed electronic transition, the internuclear distances change considerably. The expected features will be almost the same as in case (ii), the 0–0 band will, however, be very weak because of F-C principle. Nevertheless it should be possible to locate the 0–0 band at higher pressures and/or longer path lengths of the absorbing gas (reference Metropolis's analysis of the near U.V. absorption bands of SO_2 and also the CS_2 bands in the 2000A. region). The λ 3300 absorption of CS_2 is very remote from such a structure.

Case iv.—Linear upper state, electronic transition a forbidden one, moderate change in the internuclear distances. This leads to interesting possibilities. From the observed low intensity of absorption of these bands compared to the λ 2000 system, Mulliken put forward the view that the electronic transition is probably a forbidden one and may be represented by $^1\Pi_g - {}^1\Sigma_g^+$ if the molecule is linear in the


·2912·1
2983·5
30575
3125·6
657
657
3205·3
3250
3275
3305·9
3440·6

excited electronic state also; the g–g selection rule disallows the electronic transition. However, absorption bands can appear due to vibronic selection rules. For instance, the well-known near U.V. absorption spectrum of benzene has been ascribed to a forbidden electronic transition and interpreted on the basis of the selection rules appropriate to vibronic levels. Similarly in the case of CS_2, even though the transition $^1\Pi_g - {}^1\Sigma_g^+$ is not allowed by purely electronic selection rules, the excitation of vibrations of suitable symmetry either in the lower or in the upper electronic states can give rise to vibronic states of such character as to make the transition between them allowed. For instance, the excitation of the anti-symmetrical vibration ν_3 by one or any odd number of quanta in the totally symmetrical ground electronic state, $^1\Sigma_g^+$ would alter its gerade character into ungerade. Thus the transition $(000)' - (001)''$ is allowed by the vibronic selection rules. The band $(001)' - (000)''$ can also appear for similar reasons. Also $(000)' \, {}^{v1}\Pi_g - (010)'' \, {}^{v1}\Pi_u$ and $(010)' \, {}^{v1}\Pi_u - (000)'' \, {}^{v1}\Sigma_g^+$ represent allowed transitions. The various vibronic states associated with the two electronic levels $^1\Sigma_g^+$ and $^1\Pi_g$ and the vibronic allowed transitions with their polarisation characters are given by Mulliken (1941). In trying to apply these considerations to the CS_2 spectrum, one is tempted to interpret $31199 - 30529 = 670$ as $397\ (\nu_2'') + 273\ (\nu_2')$ (sum of the deformation frequencies of the lower and upper states). This is all the more encouraging because long progressions characterised with an interval of this (270 cm.$^{-1}$) magnitude were observed by the previous investigators among the long wavelength bands and Liebermann (1941), also Mulliken (1941), were inclined to ascribe 270 cm.$^{-1}$ to the bending frequency ν_2' of the upper state. Starting with these two bands as $(010)' - (000)''$ and $(000)' - (010)''$ as first members, one should find progressions of the totally symmetrical vibration ν_1' of the upper state. This feature, however, is not present in the spectrum in a convincing manner. It may be mentioned here that these two bands 31199 and 30529 are members of two separate progressions, each involving the same interval of about 450 cm.$^{-1}$ and 30529 is also the first member of one of these, but 31199 comes out only as the second member in the other progression. Also as Boltzmann factors come into play in these absorption studies the $(v00)' - (010)''$ progression should be of lower intensity, member for member, than the $(v10)' - (000)''$ progression. But no conclusive statements could be made at present as to the relative intensities of these two progressions.

Case v.—The molecule is bent in the excited electronic state. This case has been discussed at great length by Mulliken (1941) from the theoretical standpoint. In the first place, it would easily explain the violet degradation of the bands without the necessity of postulating an increase of bond energies due to the excitation of electron. As was shown by Liebermann (1941), the observed rotational structure of some of the bands in the long wavelength region consisting of simple P-R branches is not inconsistent with a bent upper state even if the degree of bending were to be as large as to reduce the SCS angle from 180° to 125°.

Molecular orbital considerations of Mulliken (1941) led him to consider that the upper electronic state of the near ultraviolet bands of CS_2 has the symmetry properties of $^1\Pi_g$ if the molecule is linear. But if the molecule is bent, as is most likely to be the case, the superposition of two electronic states of types A_2 and B_2 with their symmetry characters appropriate to the C_{2v} point group of the bent molecule gives the symmetry characteristics of the $^1\Pi_g$ state. In other words, the $^1\Pi_g$ state appropriate to the linear molecule will split into the two electronic states $^1A_2$ and $^1B_2$. Mulliken has thrown further light on these states that the CS_2 molecule should have greater bending at equilibrium and a lower energy minimum for the $^1B_2$ than for the $^1A_2$. On this basis, he attributes most of the long wavelength bands to the transition $^1B_2 - {}^1\Sigma_g^+$; the considerable bending in the $^1B_2$ state makes possible the appearance of extensive progressions of the ν_2' bending vibration of the upper state. This

expected structure has made it possible to assign a value of about 270 cm.$^{-1}$ for ν_2' of the $^{e1}B_2$ state.

It will now be attempted to fit the short wavelength bands observed in the present work into the expected vibrational scheme of the $^{e1}A_2$–$^{e1}\Sigma_g^+$ transition. Firstly, the location of this system as a whole is consistent with the higher energy of $^{e1}A_2$ with respect to $^{e1}B_2$. The molecule may not be considerably bent in this state and so one may not expect very long progressions of the ν_2' vibration such as those noticed in the $^{e1}B_2$–$^{e1}\Sigma_g^+$ transition which gives the long wavelength bands. The absence of prominent progressions of ν_2' vibration (those of 450 cm.$^{-1}$ were interpreted earlier as due to the ν_1' frequency) is probably due to the smallness of bending in the $^{e1}A_2$ state. In trying to get the allowed vibronic transitions, Mulliken (1941) made use of the gyrovibronic quantum number K, which is the quantum number for rotation about the axis of least moment of inertia in the molecule. For the case of interest to us at present, the spacing of the gyrovibronic levels varying as CK^2 becomes very large because of the constant C which would be very large because of the smallness of bending.

It is enough if the relative positions of the first members of the various 450 cm.$^{-1}$ progressions are interpreted in terms of the vibrations because the other members in each progression are already explained as due to Δv_1 0, 1, 2, 3, ...

λ 3274·6, ν 30529 is a clearly violet degraded band having a sharp red edge. The weaker, broad and diffuse absorption appearing at 30535 probably represents the R-branch; the band on the whole appears to be one of parallel type (having P-R branches only and the Q-branch missing). Being a very *strong* band occurring on the *red end* of the spectrum, it should very likely involve only very small energies in both the upper and lower electronic states. On the basis of the selection rules of Mulliken (1941), this may be designated as $(00^00)'\ ^1A_2$–$(01^10)''\ ^1\Pi_u$, a parallel band involving 397 cm.$^{-1}$ energy in the lower state and only the gyrovibronic quantum CK^2 (with K 1) in the upper state. (The single and double primes outside the brackets refer to the upper and lower electronic states as usual, the numeral on the central quantum number gives the quantum number for angular momentum along the axis of the least moment of inertia, corresponding to the l value for the linear molecule and the k value for the bent molecule.)

The next intense band, λ 3250·5, ν 30755, somewhat weaker than 30529, also looks like one of parallel type. Displaced by 226 cm.$^{-1}$ it can perhaps be interpreted as involving one quantum of the ν_2' vibration, the transition being $(01^10)'\ ^1A_2$–$(01^10)''\ ^1\Pi_u$. It may be significant to note that this 226 cm.$^{-1}$ is roughly half the 450 cm.$^{-1}$ interval observed in the prominent progressions. Under these conditions there are two possibilities of interpretation: (*a*) 450 cm.$^{-1}$ represents two quanta of the ν_2' vibration or (*b*) it represents a single quantum of the ν_1' vibration, the magnitude of $2\nu_2'$ approximately equalling ν_1' being merely accidental. The former was not tenable for reasons stated earlier. In the latter event, one should expect the Fermi resonance and a wide separation of the levels by mutual repulsion.

Probably ν 30900 and ν 30975 arise due to such a splitting. It should, however, be pointed out that 30900 is much stronger than 30975 and there is a sudden fall in intensity at 30975 in the progression starting with 30529 of which 30975 is the second member. 30975 can be represented as $(10^00)'\ ^1A_2$–$(01^10)''\ ^1\Pi_u$ and 30900 as $(12^20)'\ ^1A_2$–$(01^10)''\ ^1\Pi_u$. Fermi resonance, if present here, has reduced the intensity of one member while it has displaced the position of the other.

The imposing appearance of λ 3204·3, ν 31199 has already been mentioned. It is the second member of the 450 cm.$^{-1}$ progression starting with ν 30755 band and can thus be designated as $(11^10)'\ ^1A_2$–$(01^10)''\ ^1\Pi_u$, i.e. the location of 31199 band at a distance of 670 cm.$^{-1}$ from 30529 can be interpreted as due to the excitation of $\nu_1'+\nu_2'$ (450+226).

The band 3126·6, ν31975 has got an interesting variation in appearance as the effective absorbing path length is altered. It is one of those few main bands which appear in Plate V(*a*), at a very low effective absorbing path length of the vapour. It shows no direction of degradation. Being line-like, it has got a more prominent appearance than other more intense bands. At slightly longer paths it shows a definite degradation towards the violet but does not broaden appreciably, while most of the other bands which appear along with it in the first picture (Plate V (*a*)) develop into broad absorption regions or patches. The author is tempted to consider it as having a strong Q-branch and classify it as $(00^{0}1)'\,{}^{1}\Delta_{2}-(0^{0}0)\,{}^{1}\Sigma_{g}^{+}$ arising from the vibrationless ground state and involving one gyrovibronic quantum (K^2 (K 1) superposed on one quantum of the anti-symmetric vibration ν_3' of the upper state. If this interpretation is correct, the displacement of 31975 from 30529 by 1447 cm.$^{-1}$ can be used to estimate the value of ν_3' as 1447$-$397 1050 cm.$^{-1}$. This makes possible the interpretation of 31318 and 30661 displaced to the red respectively by 657 and 2×657 from 31975 as arising from vibrating ground state vibrating in the ν_1 mode and having the same upper level as 31975.

A perusal at the table of selection rules given by Mulliken (1941) indicates that transitions to one and the same upper level are possible from both the 397 (ν_2) and 1523 (ν_3) levels of the lower state. As most of the bands in the above progressions are found to arise from the 397 level, one can expect bands at higher absorption paths and temperatures, displaced from the above bands by 1523$-$397 1126 cm.$^{-1}$ towards the longer wavelengths. Such bands were in fact observed in the expected positions and with the expected lower intensity. These and other bands arising from the various vibrational levels of the ground electronic state will be dealt with later.

The author desires to express his gratefulness to Prof. K. R. Rao for his interest in the work, to Dr. D. S. Kothari for his encouragement and to the National Institute of Sciences of India for the award of an I.C.I. (India) Research Fellowship.

Summary

The near ultraviolet absorption bands of CS_2 in the region 3800A. to 2900A. have been photographed under various conditions of pressure and path length. Experimental evidence has been presented to indicate that there are two band systems present, the more intense of which is the short wavelength one in the region 3300A.–2900A. Long progressions were observed in this region with an interval of 450 cm.$^{-1}$ which is interpreted as representing the totally symmetrical valence vibration (ν_1') of the upper state. All the various possibilities for the geometrical configuration of the upper state were considered and attempts were made to fit in the observed regularities with the expected band spectrum appearances for the different upper states. Most probably the electronic transition is between the linear ground state and a slightly bent upper state. On the basis of the selection rules put forward by Mulliken (1941) for such a transition, the bending vibration ν_2' and the anti-symmetrical vibration ν_3' of the upper state could be assigned the frequencies of 226 cm.$^{-1}$ and 1050 cm.$^{-1}$ respectively. The accidental equality of ν_1' 450 and $2\nu_2'$ = 452 has led to a considerable displacement of the $2\nu_2'$ level due to a kind of Fermi resonance. A value of 657 cm.$^{-1}$ for the ν_1'' vibration of the lower state has been confirmed from the ultraviolet absorption spectrum.

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ANHARMONIC PULSATIONS OF A POLYTROPIC MODEL OF INDEX UNITY.

By L. D. CHATTERJI, *Mathematics Department, Allahabad University.*

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According to Rosseland the theory of anharmonic pulsations is a vital part of the pulsation theory in order to understand the form of the light and velocity curves, and it was due to him that the mathematical theory for the motion of an anharmonically pulsating gas sphere has been developed to explain the skewness of the radial velocity curve, and increase in the period of oscillation. Taking the case of a single excited mode for the homogeneous model, and retaining only the first term in the development for displacement, he was able to show that the velocity curve acquired a skewness and the period lengthened. But his results were only qualitative as it cannot account for the observed skewness and the increase in the period for comparatively small amplitude of pulsation of Cepheids. He expected that better agreement could be achieved by retaining higher order terms. But Bhatnagar and Kothari (1944), who have integrated the equation of a single excited mode for the homogeneous model for $\gamma = 5/3$, have shown that the theory of anharmonic pulsations for the homogeneous model 'cannot account for the observed skewness in the velocity-time curve of the Cepheid Variables'. Recently Schwarzschild and Savedoff (1949) have given the complete solution of the equations for the fundamental and the first mode for the standard model (polytropic index $n = 3$). Their results show that anharmonic pulsations yield practically the same period as harmonic pulsations do, though the skewness obtained is considerable yet it is smaller than that observed. Chandrika Prasad (1949) working on the same model by a different method has come to the same conclusion.

In the present paper anharmonic pulsations of a polytropic model of index unity have been studied. The results show that the effect of the first overtone gives a skewness to the velocity-time curve in the right direction, but the value obtained is smaller than that observed and the increase in the period of pulsation comes out to be slight.

The exact equation of motion for radial adiabatic pulsations of a non-rotating star, according to Rosseland (1949), is

$$\rho_0 r_0 \ddot{r}_1 = -(1+r_1)^2 \frac{\partial}{\partial r_0}\left[P_0(1+r_1)^{-2\gamma}\left(1+r_1+r_0 r_1'\right)^{-\gamma}\right]+P_0'(1+r_1)^{-2}, \quad \ldots \quad (1)$$

where P_0, ρ_0 and r_0 refer to the equilibrium values of pressure, density and distance from the centre, γ is the ratio of specific heats and r_1 is the relative displacement defined by $r = r_0(1+r_1)$. The dashes denote differentiation with respect to r_0. Expanding the equation (1) and multiplying with $\frac{r_0^3}{\gamma}$ throughout, this equation, correct to quadratic terms, is

$$r_0^3\left[\left(\frac{1}{\gamma}\right) r_0\rho_0\ddot{r}_1 - \left(3-\frac{4}{\gamma}\right)P_0' r_1 - (r_0P_0'+4P_0)r_1' - r_0P_0 r_1''\right]$$
$$+\frac{1}{2}\left[(3\gamma+1)\left(3-\frac{4}{\gamma}\right)P_0' r_0^3 r_1^2 - (3\gamma-1)P_0 r_0^4 r_1'^2 + \frac{\partial}{\partial r_0}\left\{(\gamma+1)P_0 r_0^5 r_1'^2\right\}\right.$$
$$\left.+\frac{\partial}{\partial r_0}\left\{(6\gamma-2)P_0 r_0^4 r_1 r_1'\right\}\right] = 0. \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

This is the same equation as have been obtained by Schwarzschild and Savedoff (1949).

Following Rosseland's suggestion, the relative displacement may be written as

$$r_1 = \eta_1(r_0)q_1(t)+\eta_2(r_0)q_2(t), \quad .. \quad .. \quad (3)$$

where q_1 and q_2 are functions of the time which are to be determined, and η_1 and η_2 are chosen as the solutions for the fundamental mode and first overtone derived for small amplitudes which have been obtained in the tabular form in a previous paper by the author (1951). As the functions η_1 and η_2 are not normalised to unity at the surface of the star, the relative displacement will be $(\eta_1)_s q_1+(\eta_2)_s q_2$ where $(\eta_1)_s$ and $(\eta_2)_s$ are the values at the surface.

Multiply equation (2) firstly by η_1 and then by η_2, integrate with respect to r_0 from the centre to the boundary R of the star. Due to the orthogonality of the η-functions, linear cross-terms drop out; the following equations are obtained after performing some partial integrations:

$$\left(\frac{1}{\gamma}\right)\ddot{q}_1+\frac{\sigma_1^2}{\gamma}q_1 = -\frac{1}{\int_0^R \rho_0 r_0^4\eta_1^2\,dr_0}\left[-\frac{1}{2}\left(3-\frac{1}{\gamma}\right)(3\gamma+1)\int_0^R P_0' r_0^3\eta_1 r_1^2\,dr_0\right.$$
$$+\frac{1}{2}(3\gamma-1)\int_0^R P_0 r_0^4\eta_1 r_1'^2\,dr_0+\frac{1}{2}(\gamma+1)\int_0^R P_0 r_0^5\eta_1' r_1'^2\,dr_0$$
$$\left.+(3\gamma-1)\int_0^R P_0 r_0^4\eta_1' r_1 r_1'\,dr_0\right] \quad .. \quad .. \quad .. \quad .. \quad (4)$$

$$\left(\frac{1}{\gamma}\right)\ddot{q}_2+\frac{\sigma_2^2}{\gamma}q_2 = -\frac{1}{\int_0^R \rho_0 r_0^4\eta_2^2\,dr_0}\left[-\frac{1}{2}\left(3-\frac{1}{\gamma}\right)(3\gamma+1)\int_0^R P_0' r_0^3\eta_2 r_1^2\,dr_0\right.$$
$$+\frac{1}{2}(3\gamma-1)\int_0^R P_0 r_0^4\eta_2 r_1'^2\,dr_0+\frac{1}{2}(\gamma+1)\int_0^R P_0 r_0^5\eta_2' r_1'^2\,dr_0$$
$$\left.+(3\gamma-1)\int_0^R P_0 r_0^4\eta_2' r_1 r_1'\,dr_0\right], \quad .. \quad .. \quad .. \quad (5)$$

where $\sigma_1 = \frac{2\pi}{\Pi_0}$, Π_0 being the period of the fundamental mode.

On substituting the value of r_1 from (3) on the right-hand side of equations (4) and (5) and arranging the terms in various products of the q's, we get

$$\frac{d^2q_1}{d\tau^2}+q_1 = \frac{1}{N_1\omega_1^2}\left[Aq_1^2+2Bq_1q_2+Cq_2^2\right] \quad .. \quad .. \quad .. \quad (6)$$

$$\frac{d^2q_2}{d\tau^2}+\frac{\omega_2^2}{\omega_1^2}q_2 = \frac{1}{N_2\omega_1^2}\left[Bq_1^2+2Cq_1q_2+Dq_2^2\right]; \quad .. \quad .. \quad (7)$$

here the independent variable t is replaced by

$$\tau = \frac{2\pi}{\Pi_0}t,$$

where Π_0 is the period of the fundamental mode for small amplitude, the coefficients ω_1 and ω_2 are the eigen-values corresponding to η_1 and η_2 in the pulsation problem for small amplitudes (Chatterji, 1951). The remaining six numerical constants are defined by the following equations:—

$$
\left.
\begin{aligned}
N_1 &= \int_0^R \theta r_0^4 \eta_1^2 \, dr_0. \qquad N_2 = \int_0^R \theta r_0^4 \eta_2^2 \, dr_0 \\
A &= -\left(3-\frac{4}{\gamma}\right)(3\gamma+1)\int_0^R \theta\theta' r_0^3 \eta_1^3 \, dr_0 + \frac{1}{2}(9\gamma-3)\int_0^R \theta^2 r_0^4 \eta_1 \eta_1'^2 \, dr_0 \\
&\quad + \frac{1}{2}(\gamma+1)\int_0^R \theta^2 r_0^5 \eta_1'^3 \, dr_0. \\
B &= -\left(3-\frac{4}{\gamma}\right)(3\gamma+1)\int_0^R \theta\theta' r_0^3 \eta_1^2 \eta_2 \, dr_0 + \frac{1}{2}(3\gamma-1)\int_0^R \theta^2 r_0^4 \eta_1'^2 \eta_2 \, dr_0 \\
&\quad + (3\gamma-1)\int_0^R \theta^2 r_0^4 \eta_1 \eta_1' \eta_2' \, dr_0 + \frac{1}{2}(\gamma+1)\int_0^R \theta^2 r_0^5 \eta_1'^2 \eta_2' \, dr_0. \\
C &= -\left(3-\frac{4}{\gamma}\right)(3\gamma+1)\int_0^R \theta\theta' r_0^3 \eta_1 \eta_2^2 \, dr_0 + \frac{1}{2}(3\gamma-1)\int_0^R \theta^2 r_0^4 \eta_1 \eta_2'^2 \, dr_0 \\
&\quad + (3\gamma-1)\int_0^R \theta^2 r_0^4 \eta_1' \eta_2 \eta_2' \, dr_0 + \frac{1}{2}(\gamma+1)\int_0^R \theta^2 r_0^5 \eta_1' \eta_2'^2 \, dr_0 \\
D &= -\left(3-\frac{4}{\gamma}\right)(3\gamma+1)\int_0^R \theta\theta' r_0^3 \eta_2^3 \, dr_0 + \frac{1}{2}(9\gamma-3)\int_0^R \theta^2 r_0^4 \eta_2 \eta_2'^2 \, dr_0 \\
&\quad + \frac{1}{2}(\gamma+1)\int_0^R \theta^2 r_0^5 \eta_2'^3 \, dr_0
\end{aligned}
\right\} \qquad \ldots \quad (8)
$$

where θ is the Emden variable for the polytrope $n = 1$, and its values are taken from the *Mathematical Tables*, Vol. 2, of the British Association for the Advancement of Science (1932). In equation (8) the integrals have been taken from the centre to the surface of the star, and the dashes denote derivatives with respect to r_0. These integrals have been evaluated for the polytrope $n = 1$ taking $\gamma = 5/3$.

The values of the six constants are found to be as follows:

$$
\begin{aligned}
N_1 &= 14{\cdot}766659 \qquad N_2 = 3{\cdot}483853 \\
A &= 11{\cdot}392750 \qquad B = -0{\cdot}863641 \\
C &= 14{\cdot}927878 \qquad D = -24{\cdot}594280
\end{aligned}
$$

With these numerical values, equations (6) and (7) become

$$
\frac{d^2 q_1}{d\tau^2} + q_1 = 3{\cdot}33991 q_1^2 - {\cdot}50637 q_1 q_2 + 4{\cdot}37627 q_2^2 \qquad \ldots \quad (9)
$$

$$
\frac{d^2 q_2}{d\tau^2} + 6{\cdot}5671 q_2 = -1{\cdot}07315 q_1^2 + 37{\cdot}0985 q_1 q_2 - 30{\cdot}56063 q_2^2 \qquad \ldots \quad (10)
$$

In order to solve these equations, they are put in the form

$$\frac{d^2q_1}{d\tau^2}+q_1 = A_1q_1^2+2B_1q_1q_2+C_1q_2^2 \quad .. \quad .. \quad .. \quad (11)$$

$$\frac{d^2q_2}{d\tau^2}+\beta_2q_2 = A_2q_1^2+2B_2q_1q_2+C_2q_2^2 \quad .. \quad .. \quad .. \quad (12)$$

where $\beta_2 = 6{\cdot}5671$. $A_1 = \ 3{\cdot}33991$, $B_1 = -0{\cdot}253186$, $C_1 = \ 4{\cdot}37627$,
$A_2 = -1{\cdot}07315$, $B_2 = 18{\cdot}54925$, $C_2 = -30{\cdot}56065$.

Solutions of these equations are to be sought which are periodic with the same period for q_1 and q_2. Let

$$q_1 = a_0+a_1\cos n\tau+a_2\cos 2n\tau+a_3\cos 3n\tau+ \quad .. \quad .. \quad (13)$$

$$q_2 = b_0+b_1\cos n\tau+b_2\cos 2n\tau+b_3\cos 3n\tau+ \quad .. \quad .. \quad (14)$$

where $a_0, a_1, \ldots, b_0, b_1, \ldots$, and n are constants to be found out.

These values of q_1 and q_2 are substituted in the equations (11) and (12) and all the products of the cosines are expressed as sums of the cosines. Then putting the constant term and the coefficients of $\cos kn\tau$ for different k, separately equal to zero, the following equations are obtained :—

$$(k^2n^2-1)a_k+A_1\left[\frac{1}{2}\sum_{i=0}^{k}a_ia_{k-i}+\sum_{i=0}^{\infty}a_ia_{k+i}\right]$$
$$+B_1\left[\sum_{i=0}^{k}a_ib_{k-i}+\sum_{i=0}^{\infty}(a_ib_{k+i}+a_{k+i}b_i)\right]$$
$$+C_1\left[\frac{1}{2}\sum_{i=0}^{k}b_ib_{k-i}+\sum_{i=0}^{\infty}b_ib_{k+i}\right]=0. \quad .. \quad .. \quad .. \quad .. \quad (15)$$

$$(k^2n^2-\beta_2)b_k+A_2\left[\frac{1}{2}\sum_{i=0}^{k}a_ia_{k-i}+\sum_{i=0}^{\infty}a_ia_{k+i}\right]$$
$$+B_2\left[\sum_{i=0}^{k}a_ib_{k-i}+\sum_{i=0}^{\infty}(a_ib_{k+i}+a_{k+i}b_i)\right]$$
$$+C_2\left[\frac{1}{2}\sum_{i=0}^{k}b_ib_{k-i}+\sum_{i=0}^{\infty}(b_ib_{k+i})\right]=0. \quad .. \quad .. \quad .. \quad .. \quad (16)$$

These infinite number of infinite equations are solved by successive approximations by a method as given by Chandrika Prasad (1949). The value of $a_0, b_0, b_1, a_2, b_2, \ldots$, are obtained in terms of a_1.

A solution for the polytrope $n = 1$ of the equations (11) and (12) is found out by choosing $a_1 = 0{\cdot}06$, so as to make the surface amplitude equal to 0·08, that is 8% of the stellar radius, which is of the order observed. The solution is found to be :—

$$q_1 = 0{\cdot}006148+0{\cdot}06\cos n\tau-0{\cdot}002076\cos 2n\tau+0{\cdot}000052\cos 3n\tau, \quad .. \quad .. \quad (17)$$

$$q_2 = -0{\cdot}000373-0{\cdot}000398\cos n\tau-0{\cdot}000803\cos 2n\tau+0{\cdot}000298\cos 3n\tau, \quad .. \quad (18)$$

where $n^2 = 0{\cdot}966161$.

If ζ denotes the surface amplitude due to the fundamental mode and the first overtone, then

$$\zeta = (\eta_1)_s q_1 + (\eta_2)_s q_2 .$$

Here Chatterji (1951) $(\eta_1)_s = 1{\cdot}218532$ and $(\eta_2)_s = -1{\cdot}251806$.

Therefore $\zeta = 0{\cdot}007959 + 0{\cdot}073610 \cos n\tau - 0{\cdot}001525 \cos 2n\tau - 0{\cdot}000310 \cos 3n\tau$. (19)

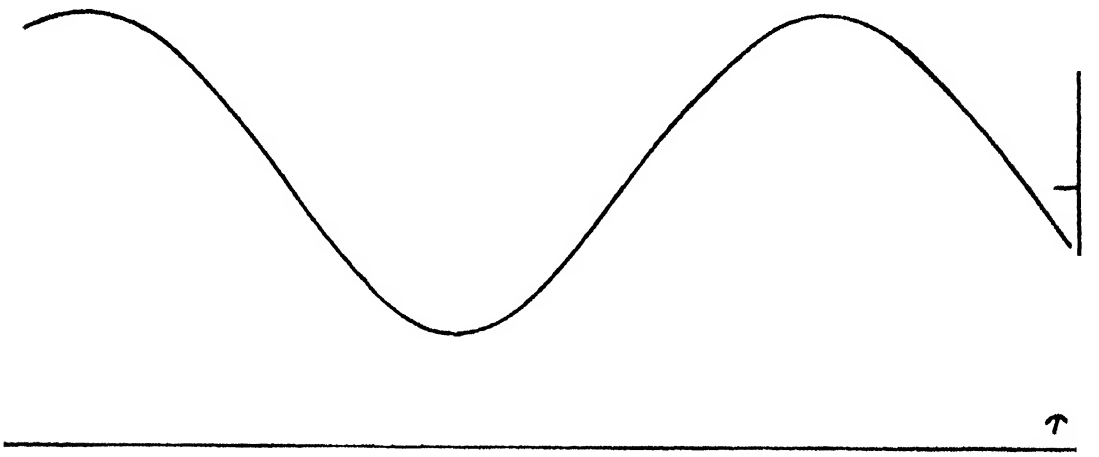

Fig. 1. Displacement curve for the polytrope $n = 1$.

The shape of the displacement curve obtained from this equation is shown in the diagram. If K (skewness) is the ratio of the time of decline from maximum to minimum to the time of rise to maximum, then K for the above curve is 1·176. The increase in the period is found to be slight, being only 1·74%.

I am indebted to Prof. A. C. Banerji for his keen interest in this paper.

Summary.

The anharmonic pulsations of a polytropic model of index unity are investigated. It is found that the first overtone gives a skewness to the radial velocity curve. The value comes out to be small when compared with the observed value, and the increase in the period is found to be slight.

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A NOTE ON ENERGY LEVELS OF HYDROGEN ATOM WITH FINITE SIZE NUCLEUS.

By PYARELAL, *Delhi College, Delhi and* P. L. BHATNAGAR, F.N.I., *St. Stephen's College, Delhi.*

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Rose (1951) and others have investigated the effect of the finite size of the nucleus in a number of problems. They take a penetrable model of the nucleus in which the wave functions inside and outside (the nucleus) are made to join analytically at the boundary. We on the other hand for our non-relativistic treatment of the hydrogen atom take an impenetrable model for the nucleus and make the wave function vanish at the boundary. For this the Schroedinger wave function Ψ satisfies here the boundary conditions (i) $\Psi(r)=0$ at $r=a_0$, the radius of the nucleus, (ii) $\Psi(r)\to 0$ as $r\to\infty$ as compared to the conventional case in which (i) $r\Psi(r)$ is finite at $r=0$, and (ii) $\Psi(r)\to 0$ as $r\to\infty$. This problem is in a way complementary to that of Sommerfeld and Welker (1938) in which they discuss the solution of Schroedinger equation for a hydrogen atom enclosed in a sphere of finite radius R with the nucleus (proton) at the centre. The problem of the bounded oscillator was considered by Auluck and Kothari (1945). As the energy levels are raised as an effect of the finite size of the nucleus it is likely to have some relevance in connection with the theory of Lamb and Retherford (1947) shift. The shift which is largest for the s levels is in the case of $2s$ of the order of ·23 wave numbers for a_0 of the order of $\frac{\hbar}{MC}=2\times 10^{-14}$ cm.

The Schroedinger equation for the hydrogen atom* is

$$\nabla^2\Psi+\left(E+\frac{2}{r}\right)\Psi=0 \qquad .. \quad .. \quad .. \quad (1)$$

The radial part of Ψ satisfies the usual equation

$$\frac{d^2R}{dZ^2}+\frac{2}{Z}\frac{dR}{dZ}+\left\{-\frac{1}{4}+\frac{k}{Z}-\frac{l(l+1)}{Z^2}\right\}R=0 \quad .. \quad .. \quad .. \quad (2)$$

$$(l=0,\ 1,\ 2,\ \ldots)$$

where

$$Z=\frac{2r}{k},\quad k=\frac{1}{\sqrt{-E}} \qquad .. \quad .. \quad .. \quad .. \quad (3)$$

The boundary conditions to be satisfied by R are:

(i) $R(Z)\to 0$ as $Z\to\infty$

(ii) $R(Z_0)=0$ at $Z=Z_0$ $(Z_0>0)$ where $Z_0=\frac{2a_0}{k}$.

The required solution is the confluent hypergeometric function

$$R=W_{k,\,l+\frac{1}{2}}(Z)/Z \qquad .. \quad .. \quad .. \quad .. \quad (4)$$

---

* Here the unit of r is the Bohr radius a_H and the unit of energy is Rydberg constant $\frac{e^2}{2a_H}$.

as pointed out by Eddington (1927) and Sugiura (1927) and later developed by Hartree (1928)

The vanishing of R at infinity is evident from the asymptotic form for $W_{k,l+\frac{1}{2}}(Z)$ (Whittaker and Watson, 1927) for large Z

$$W_{k,l+\frac{1}{2}}(Z) = e^{-\frac{1}{2}Z}Z^k\left[1 + \sum_{n=1}^{\infty}\frac{\{m^2-(k-\frac{1}{2})^2\}\{m^2-(k-\frac{3}{2})^2\}\ldots\{m^2-(k-n+\frac{1}{2})\}}{n!\,z^n}\right]$$

The boundary condition at $Z = Z_0$ requires

$$W_{k,l+\frac{1}{2}}(Z_0) = 0 \qquad \ldots\ \ldots\ \ldots\ \ldots \qquad (5)$$

The expansion of $W_{k,l+\frac{1}{2}}(Z)$ for small Z (Hartree, 1928) is

$$W_{k,l+\frac{1}{2}}(Z) = \frac{e^{-\frac{1}{2}Z}Z^k}{\Gamma(-k-l)\Gamma(-k+l+1)}\left[\sum_{m=0}^{2l}(-1)^{m+1}\frac{\Gamma(-k-l+m)\Gamma(2l+1-m)}{m!}Z^{-k-l+m}\right.$$
$$\left. - \sum_{m=2l+1}^{\infty}\frac{\Gamma(-k-l+m)Z^{-k-l+m}}{m!\,(m-2l-1)!}\{\log Z+\psi(-n-l+m)-\psi(m-1)-\psi(m-\tfrac{5}{2})\}\right]$$
$$\ldots \qquad (6)$$

As will be seen later, the effect of the nuclear size on energy levels gets very small for large l, we shall therefore restrict ourselves here to the cases $l = 0$ (s states) and $l = 1$ (p states) for which we can write

$$W_{k,\frac{1}{2}}(Z) = \frac{e^{-\frac{1}{2}Z}}{\Gamma(1-k)}\left[1+\frac{(-k)}{1}\left(\frac{1}{-k}-\frac{1}{1}\right)Z+\frac{(-k)(1-k)}{2\,.\,1^2}\left(\frac{1}{-k}+\frac{1}{1-k}-\frac{2}{1}-\frac{1}{2}\right)Z^2+\ldots\right.$$
$$\left.+\left(\log Z+2\gamma+\psi(1-k)+\frac{1}{k}\right)\left\{(-k)Z+\frac{(-k)(1-k)}{2\,.\,1^2}Z^2+\ldots\right\}\right] \qquad \ldots \qquad (7)$$

$$W_{k,\frac{3}{2}}(Z) = \frac{e^{-\frac{1}{2}Z}}{\Gamma(2-k)}\frac{1}{Z}\left[2-(-1-k)Z+\frac{(-1-k)(-k)}{2\,.\,1}Z^2+\frac{(-1-k)(-k)(1-k)}{3\,.\,2\,.\,1}\times\right.$$
$$\left\{\frac{1}{1-k}-(\tfrac{1}{3}+\tfrac{1}{2}+1)\right\}Z^3+\ldots+[\log Z+2\gamma+\psi(1-k)]\left\{\frac{(-1-k)(-k)(1-k)}{3\,.\,2\,.\,1}Z^3\right.$$
$$\left.\left.+\frac{(-1-k)(-k)(1-k)(2-k)}{4\,.\,3\,.\,2\,.\,1^2}Z^4+\ldots\right\}\right] \qquad \ldots \qquad (8)$$

where γ is Euler's constant 0·577.

First for the conventional case,

$$\Psi(r) \text{ is finite at } r = 0;$$

we shall show that k must be a positive integer.

For s states :

$$R = \frac{1}{Z}W_{k,\frac{1}{2}}(Z)$$
$$= \frac{e^{-\frac{1}{2}Z}}{\Gamma(2-k)}\left[\frac{1-k}{Z}+\frac{(1-k)(-k)}{1}\left(\frac{1}{-k}-\frac{1}{1}\right)+\ldots-\left\{(1-k)\log Z+2\gamma(1-k)+\right.\right.$$
$$\left.\left.(1-k)\,\psi(1-k)+\frac{1-k}{k}\right\}\left\{k-\frac{k(1-k)}{2\,.\,1}Z+\ldots\right\}\right]$$

Now if the above expression is not to diverge at $Z = 0$, the coefficients of $\frac{1}{Z}$ and $\log Z$ must vanish, i.e. $k = 1$. Similarly it is readily seen that k admits only the other values 2, 3, 4.... Taking now $W_{k,\frac{1}{2}(Z)}$ it similarly follows that the possible values of k are 2, 3, 4.... , the lowest value being 2.

As $W_{k,l+\frac{1}{2}(Z)}$ vanishes at $Z = Z_0$ ($Z_0 > 0$), we have from the series expansions (7) and (8)

$$\left[1+\frac{(-k)}{1}\left(\frac{1}{-k}-\frac{1}{1}\right)Z_0+\frac{(-k)(1-k)}{2.1^2}\left(\frac{1}{-k}+\frac{1}{1-k}-\frac{2}{1}-\frac{1}{2}\right)Z_0^2+\ldots\right.$$
$$\left.+\left(\log Z_0+2\gamma+\psi(1-k)+\frac{1}{k}\right)\left\{(-k)Z_0+\frac{(-k)(1-k)}{2.1^2}Z_0^2+\ldots\right\}\right]=0$$

(for $l = 0$)

and

$$\left[1+\frac{k+1}{1}Z_0+\frac{(-k)(-k-1)}{2.1}Z^2+\frac{(1-k)(-k)(-k-1)}{3.2.1}Z_0^3\left(\frac{1}{1-k}-(\tfrac{1}{3}+\tfrac{1}{2}+1)\right)+\ldots\right.$$
$$\left.+\frac{(1-k)(-k)(-1-k)}{3.2.1}\left(\log Z_0+2\gamma+\psi(1-k)\right)\left\{Z_0^3+\frac{2-k}{4.1}Z_0^4+\ldots\right\}\right]=0$$

(for $l = 1$)

Writing for convenience $2a_0 = \sigma$ and noting that

$$kZ_0 = 2a_0 = \sigma$$

we obtain

$$1+\frac{1+k}{k}\sigma+\frac{2+k-5k^2}{4k^2}\sigma^2+\ldots=(\log\sigma+2\gamma-\log k+\frac{1}{k}+\psi(1-k))\left\{\sigma+\frac{1-k}{2k}\sigma^2+\ldots\right\}$$

(for $l = 0$) .. (9)

and

$$2+\frac{1+k}{k}\sigma+\frac{k+k^2}{2k^2}\sigma^2+\ldots=\frac{(1-k)(-1-k)}{6k^2}\sigma^3(\log\sigma/k+2\gamma+\psi(1-k))\left\{1+\frac{2-k}{4k}\sigma+\ldots\right\}$$

(for $l = 1$) .. (10)

Writing $k = 1+\beta$ we have, as $\sigma \ll 1$, the following approximate expressions [from equations (10) and (11)] for

$$\beta = \sigma+\sigma^2(\log\sigma+\gamma-1)+O(\sigma^3) \quad .. \quad .. \quad .. \quad (9a)$$

(1s state)

Similarly for the next level ($k = 2$) we have, writing $k = 2+\beta$,

$$\beta = \sigma+\sigma^2(\log\sigma+\gamma-\log 2-\tfrac{1}{4})+O(\sigma^3) \quad .. \quad .. \quad (9b)$$

(2s state)

$$\beta = \tfrac{1}{16}\sigma^3+O(\sigma^4) \quad .. \quad .. \quad .. \quad .. \quad .. \quad (10b)$$

(2p state)

and for the next ($k = 3$) writing $k = 3+\beta$

$$\beta = \sigma+\sigma^2(\log\sigma+\gamma-\log 3-\tfrac{1}{6})+O(\sigma^3) \quad .. \quad .. \quad (9c)$$

(3s state)

$$\beta = \tfrac{2}{27}\sigma^3+O(\sigma^4) \quad .. \quad .. \quad .. \quad .. \quad .. \quad (10c)$$

(3p state)

Numerical values for the shifts in the energy levels are given in the following table for (i) $a_0 = \hbar/MC$, (ii) $a_0 = \frac{e^2}{MC^2}$, where M is the mass of the proton.

Table for level-shifts in Rydberg units.

Level	$a_0 = \frac{\hbar}{MC}$	$a_0 = \frac{e^2}{MC^2}$
$1s$	$1{\cdot}6 \times 10^{-5}$	$1{\cdot}2 \times 10^{-7}$
...	....	....
$2s$	2×10^{-6}	$1{\cdot}5 \times 10^{-8}$
$2p$	8×10^{-18}	3×10^{-24}
$3s$	6×10^{-7}	$4{\cdot}4 \times 10^{-9}$
$3p$	3×15^{-18}	1×10^{-24}

(It may be noted that the observed Lamb-Retherford shifts for the $2s-2p$ levels is 3×10^{-7} Rydberg units.)

The authors are thankful to Prof. D. S. Kothari for his kind interest in this work.

ABSTRACT.

In this paper the solution of the Schroedinger equation for a hydrogen atom with a finite size impenetrable nucleus is worked out.

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STUDIES ON CYTOCHEMISTRY OF HORMONE ACTION.

PART X.—THE HORMONAL MODIFICATION OF ALKALINE PHOSPHATASE ACTIVITY IN THE TESTIS AND IN SOME MALE GENITAL ACCESSORIES OF THE GUINEAPIG.

by AMIYA B. KAR, *Ph.D., Senior Research Fellow, N.I.S.I., and* ASOK GHOSH, *M.Sc., Central Drugs Laboratory, Government of India, Calcutta.*

(Communicated by Dr. B. Mukerji, F.N.I.)

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THE PROBLEM.

The present paper embodies the extent to which the alkaline phosphatase activity in the testis and in some male genital accessories of the guineapig can be influenced by various hormones.

REVIEW OF THE LITERATURE.

Kabat and Furth (1941) observed that only slight alkaline phosphatase activity is present in the spermatogenic cells of the adult human testis but the basement membrane of the tubules exhibits more prominent reactions for the enzyme. Recently, Bern (1949) made a comparative study of the distribution of alkaline phosphatase in the male genital system of several species of mammals including the species under report. In an earlier paper Gomori (1941) reported the occurrence of this enzyme in the testis of the rabbit and the guineapig and the details of enzymatic distribution in the two species, as given by Bern (1949), agree with those presented by the former author. Bourne (1943) also observed the presence of alkaline phosphatase activity in the guineapig's testis. Dempsey *et al.* (1949) noted that in the rat this enzyme is demonstrable both in the tubules and in the intertubular tissue. After hypophysectomy the phosphatase disappears from the testicular components but replacement therapy with whole pituitary powder causes a return of the enzyme to its original distribution and intensity in all the elements. Wislocki (1949) reported the presence of alkaline phosphatase in the interstitial cells and in the tubular elements of the testis of two species of deer, *Odocoileus virginianus borealis* and *Cervus nippon*.

Kabat and Furth (1941) observed that alkaline phosphatase activity is entirely absent from the epithelium of the adult human prostate and seminal vesicles. The endothelium of the capillaries of the latter, however, gives intense reactions for the enzyme whereas the mascular stroma of both the organs contains only a trace of the phosphatase. Gomori (1941) noted that marked enzyme activity is present in the bladder epithelium of the rabbit and the guineapig. Bourne (1943) obtained negative Gomori reactions for alkaline phosphatase activity in the vas deferens and in the seminal vesicles of the guineapig. Zorzoli and Stowell (1947) noted the presence of strong alkaline phosphatase activity in the mascular stroma of the bladder of the rat, mouse, and the guineapig. They also remarked on the pronounced enzyme activity in the nuclei of the epithelium of guineapig's vas deferens and the subepithelial connective tissue of rat's epididymis. Atkinson (1948) reported that marked phosphatase activity is present in the stromal elements of the seminal vesicle of the adult mouse. Occasional traces of the enzyme are

also demonstrable in the nuclei of the mucosal epithelium. Castration causes a diminution of phosphatase activity which, however, is restored on replacement therapy with androgen. Soulairac and Thibault (1948) demonstrated that intense enzyme activity is visible in the vas deferens, seminal vesicles, prostate and Cowper's glands of the rat. Castration causes a suppression of phosphatase activity which can be re-established by androgen therapy. Desoxycorticosterone acetate is only partially effective in restoring the enzyme activity but estrogen has no effect in this respect. Dempsey *et al.* (1949) observed pronounced phosphatase activity in the stroma and in the capillaries immediately underneath the epithelium of the rat's seminal vesicle. After hypophysectomy or gonadectomy, the enzyme activity considerably declined or disappeared. The restoration of the normal enzymatic complement is accomplished by the injection of pituitary powder or testosterone into the operated rats. Wislocki (1949) noted the occurrence of alkaline phosphatase in the seminal vesicles and in the ductus epididymidis of the two species of deer referred to in the previous paragraph. Bern (1949) studied the distribution of this enzyme in the male genital accessories of several species of mammals including the guineapig.

In the testis of juvenile sparrows the enzyme is present in the seminiferous tubules and in the endothelium of the interstitial blood vessels (Kar, 1951*a*). Desoxycorticosterone acetate treatment causes a pronounced loss of phosphatase activity from practically all the testicular components. The distribution of the enzyme in the testis of the adult pigeon exhibits a pattern which is more or less similar to that in the sparrow (Kar, 1951*b*). However, in the pigeon the Leydig and the fibroblast cells of the interstitium also show pronounced phosphatase activity. Treatment with sexual hormones is associated with a marked inhibition of enzymatic activities in the testicular components. There is, unfortunately, no report of the presence of alkaline phosphatase in the ductus deferens of birds.

A careful perusal of the works cited in the foregoing paragraphs makes it evident that considerable efforts have been made to study the distribution of alkaline phosphatase in the male genital system of different species of animals, but attempts to modify its activities by hormonal treatments have been rather meagre. We would like to emphasise in this connection that the component organs of the male genitalia are nicely suited for studies on hormone-enzyme relationships and extensive researches on this system are sure to adduce many valuable evidences to the current thesis that the hormonal actions are mediated through the modifications of enzymatic activities.

Experimental.

The details regarding the allotment of the animals for receiving treatments and the dosage used for different hormones have already been presented in a previous paper of this series (Kar and Ghosh, 1952). The male genital organs of normal and hormone-treated guineapigs were carefully dissected out on autopsy and were processed according to the technique of Gomori (1941) for the demonstration of alkaline phosphatase. The tissue sections were incubated in the substrate mixture for three hours and were finally mounted without any counterstaining.

Results.

A. *Testis.*

Controls: The basement membrane of the tubules stains positively for the phosphatase. The enzyme activity is present in all the tubular elements. But in the spermatogonia and in the spermatocytes the phosphatase activity is more intense in the nucleus than in the cytoplasm. The Sertoli cells alone show uniform enzyme activity in the nucleus as well as in the cytoplasm (Pl. VII, fig. 1).

Phosphatase is also present in the chromosomes of the dividing tubular elements. Among the intertubular elements the endothelium of the blood vessels and the nucleus of the Leydig cells show intense phosphatase activity. The cytoplasm of the latter gives only a faint reaction for the enzyme.

Testosterone propionate treatment: There is a total loss of phosphatase activity from practically all the testicular components (Pl. VII, fig. 2).

Desoxycorticosterone acetate treatment: A pronounced loss of phosphatase activity is evident in the testis. However, small amounts of the enzyme are retained in the spermatogonia, the spermatocytes and in the endothelium of the intertubular blood vessels (Pl. VII, fig. 3).

Progesterone treatment: An overall reduction in phosphatase activity is evident in the organ. The basement membrane of the tubules stains faintly but the cellular elements show positive reactions for the enzyme. However, the reactions here are much less intense than in the tubular elements of the control animals (Pl. VII, fig. 4). In the interstitium the marked phosphatase activity is retained in the endothelium of the blood vessels but a definite loss is evident in the Leydig cells.

TABLE I.

The distribution of alkaline phosphatase in the male genital accessories of normal and hormone-treated guineapigs.

	Controls.	Androgen treated.	DCA-treated.	Progesterone treated.	Estradiol treated.	Stilbestrol treated.	Gonadotrophic hormone treated.
TESTIS							
Basement Membrane ..	+ +	–	–	+(F)	–	+ (F)	+(F)
Seminiferous epithelium ..	+ +	–	+(F)	+	–	+	+(F)
Interstitium ..	+ +	–	+(F)	+	–	+	+(F)
SEMINAL VESICLE							
Epithelium	+ +	+	+	+	+	+(F)	+ +
Fibro-muscular stroma ..	–	–	–	–	–	+(F)	–
PROSTATE							
Epithelium	+(F)	–	–	–	+ +	+	+(F)
Basement membrane ..	–	–	–	–	–	–	–
EPIDIDYMIS							
Epithelium	+ + n	+ + n	+ + n	+ + n	+ + n	+ + n	+ + n
Basement membrane ..	+ +	+	+ +	+ +	+ +	+	+ +
VAS DEFERENS							
Epithelium	+(F)	–	+(F)	+(F)	+ n(F)	+ + n	+ n(F)
Fibro-muscular stroma ..	–	–	–	–	+ +	+ +	–

Legend:— + = Positive reaction.
+ + = Very strong positive reaction.
– = Negative reaction.
+(F) = Faint reaction.
n = Only nuclear phosphatase activity.

Estradiol dipropionate treatment: Typical castration effects are seen in the testis of the treated animals. Total loss of phosphatase activity is clearly visible in the testicular components.

Diethylstilbestrol treatment: The enzymatic responses to this hormone treatment strikingly resemble those elicited by the luteoid. The basement membrane of the tubules gives only a faint reaction for the enzyme (Pl. VII, fig. 5). Moderate nuclear phosphatase activity is retained in the tubular elements. Similar reactions are also seen in the Leydig cells but the endothelium of the interstitial blood capillaries exhibits marked phosphatase activity.

Gonadotrophic hormone treatment: Stimulation of some components of the testis is discernible upon histological examination. But a pronounced loss of enzymatic activity is visible in our preparations (Pl. VII, fig. 6; also see Table 1).

B. *Seminal vesicle.*

Controls: Seminal vesicle has an external muscular layer of longitudinal fibres and an internal circular muscle layer. The mucosa is considerably pleated in appearance and its epithelium is of the columnar type. The muscle layers are entirely negative for the phosphatase but spectacular enzyme activity is visible in the mucosa (Pl. VIII, fig. 7). The reactions are so intense that the contour of the epithelial cells is totally obscured by the granular deposits of cobalt sulfide.

Testosterone propionate treatment: The muscle layers stain negatively for the enzyme. There is a definite reduction of phosphatase activity from the epithelial cells of the mucosa. This enzymatic loss appears to be more pronounced in the cytoplasm than in the nucleus (Pl. VIII, fig. 8). Marked phosphatase activity, however, is retained in the endothelium of the blood capillaries located in the axial portion of the mucosal pleats.

Desoxycorticosterone acetate treatment: Muscle layers give negative reactions for the enzyme. There is only a slight loss of phosphatase activity from the mucosa. This is evident from the fact that the cellular contours are clearly distinguishable in our preparations (Pl. VIII, fig. 9) and not obscured by cobalt sulfide deposits as in the control animals (Table I and text-fig. 1).

Progesterone treatment: Muscle layers stain negatively for the phosphatase. The enzymatic responses in the mucosa appear to be the same as in the DCA-treated animals.

Estradiol dipropionate treatment: No phosphatase activity is visible in the muscle layers. There is a slight enzymatic loss from the mucosa and the reactions appear to be similar as in the DCA-treated animals.

Diethylstilbestrol treatment: The organ presents an infantile appearance. The longitudinal muscle layer is negative for the phosphatase but slight reactions are given by the nuclei of the circular muscle fibres. The sub-mucus region shows maximum phosphatase activity. This is evident in the nucleus of the cells in this region as well as in the endothelium of the blood vessels (Pl. VIII, fig. 10). Marked enzyme activity is also seen in the connective tissue extending into the axial portion of the slightly pleated mucosal folds. The epithelial cells of the mucosa, however, give only a faint reaction in the nucleus.

Gonadotrophic hormone treatment: Muscle layers stain negatively for the phosphatase. In the mucosa the intensity of reaction is comparable to that in the controls.

C. *Prostate.*

Controls: No phosphatase activity is seen in either the basement membrane surrounding an alveolus or in the fibro-muscular septum separating two alveoli. Only negligible amounts of the enzyme are present in the columnar epithelial cells of the mucosa (Pl. VIII, fig. 11; Table I and text-fig. 1).

Testosterone propionate treatment: Practically no enzyme activity is seen in the prostatic components.

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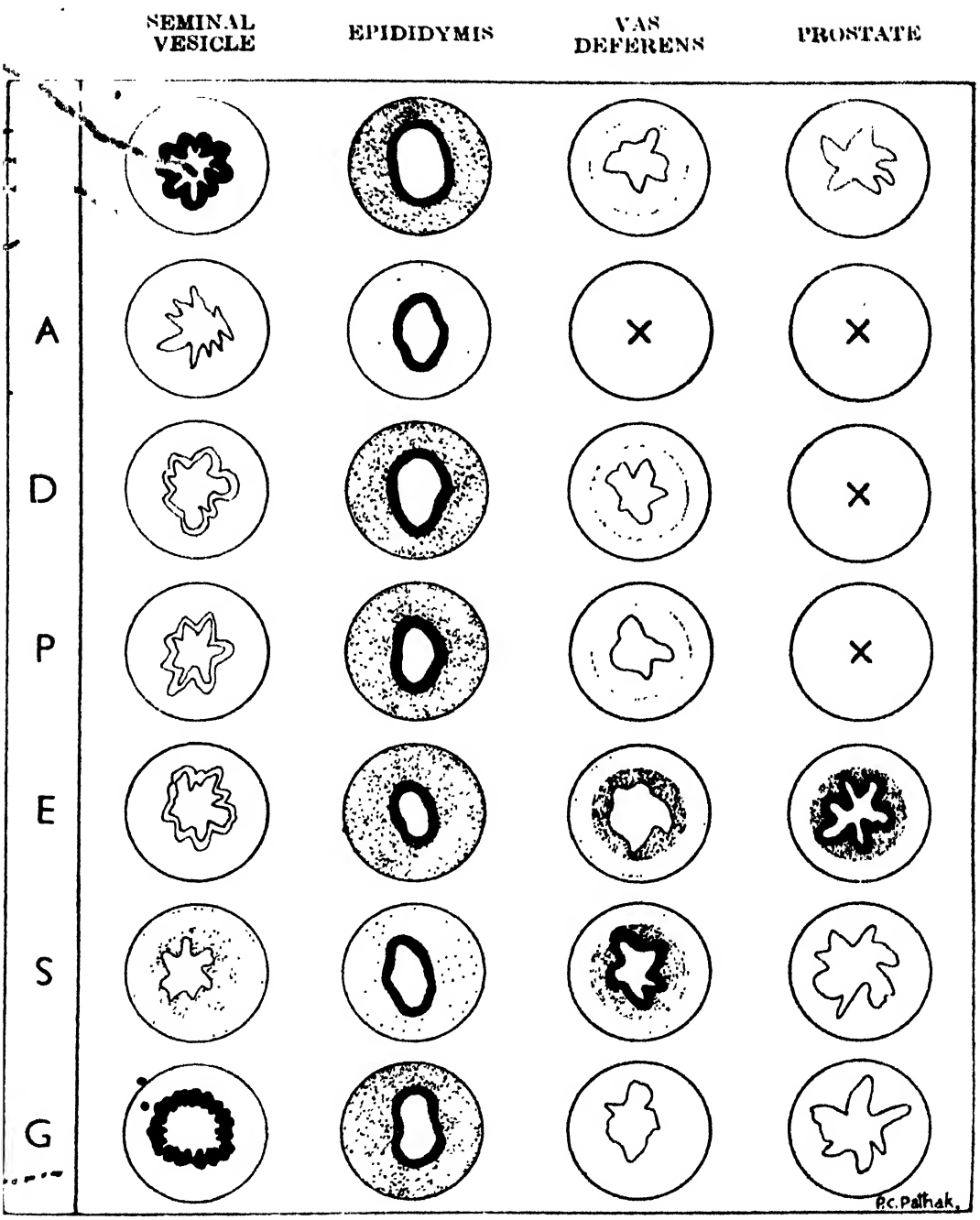

TEXT-FIG. 1. Diagram to show changes in the distribution of alkaline phosphatase in the male genital accessories of normal and hormone-treated guineapigs. Heavy dark line indicates very pronounced phosphatase activity in the mucosa, double thin lines less intense activity, and single thin line mere positive reaction in the same component. Stippled areas indicate locations of stromal phosphatase activity. Closely stippled areas correspond to strong enzyme activity zones and sparsely stippled areas indicate locations where the reactions are much less intense. C, controls; A, testosterone propionate treated; D, desoxycorticosterone acetate treated; P, progesterone treated; E, estradiol dipropionate treated; S, diethylstilbestrol treated; G, gonadotrophic hormone treated; and X, negative reaction.

Desoxycorticosterone acetate treatment: The enzymatic response to the corticoid treatment is entirely negative.

Progesterone treatment: The phosphatase does not show any response to the luteoid treatment.

Estradiol dipropionate treatment: The basement membrane and the inter-alveolar septum stain negatively for the enzyme. Positive reactions for the phosphatase, however, are given by the connective tissue extending into the axial portion of the slightly pleated mucosa (Pl. VIII, fig. 12). The epithelial cells of the mucosa also exhibit prominent phosphatase activity.

Diethylstilbestrol treatment: Only moderate reactions for the phosphatase are visible in the nucleus of the epithelial cells of the mucosa (Pl. IX, fig. 13). In other components the enzyme activity is practically absent.

Gonadotrophic hormone treatment: The nuclei of the mucosal epithelial cells stain faintly. In other components the phosphatase activity is nil.

D. *Epididymis.*

Controls: The basement membrane of the tube stains intensely for the phosphatase (Pl. IX, fig. 14). The nucleus of the epithelial cells shows marked enzyme activity but responses are very slight in the cytoplasm.

Testosterone propionate treatment: There is a reduction in phosphatase activity in the basement membrane of the tube but the reactions in the epithelial cells are more or less similar to that in the controls (Pl. IX, fig. 15).

Desoxycorticosterone acetate treatment: The basement membrane of the tube and the nucleus of the epithelial cells stain intensely as in the control animals but there is a total loss of phosphatase activity from the cytoplasm of the latter elements.

Progesterone treatment: The reactions are more or less similar to those observed in the DCA-treated animals.

Estradiol dipropionate treatment: The responses appear to be the same as in the control animals.

Diethylstilbestrol treatment: There is a definite loss of phosphatase activity from the basement membrane of the tube as well as from the cytoplasm of the epithelial cells but the nuclear enzyme activity is retained to the control level (Pl. IX, fig. 16; Table I and text-fig. 1).

Gonadotrophic hormone treatment: The enzymatic responses are more or less similar to that in the control animals.

E. *Vas deferens.*

Controls: The muscle layers are negative for the phosphatase. The endothelium of the blood vessels in the sub-mucosal region and the mucosal epithelial cells show only a faint reaction for the enzyme (Pl. IX, fig. 17).

Testosterone propionate treatment: The components of the vas deferens are entirely negative for the phosphatase.

Desoxycorticosterone acetate treatment: The reactions are more or less same as in the control animals.

Progesterone treatment: The phosphatase responses are comparable to those encountered in the vas deferens of the control animals.

Estradiol dipropionate treatment: The muscle layers give faint positive reactions for the phosphatase but the sub-mucosal connective tissues and the endothelium of the blood vessels in this region show intense enzyme activity (Pl. IX, fig. 18; Table I and text-fig. 1). Only negligible quantities of the phosphatase are present in the nucleus of the epithelial cells of the mucosa but the cytoplasm is practically negative for the enzyme.

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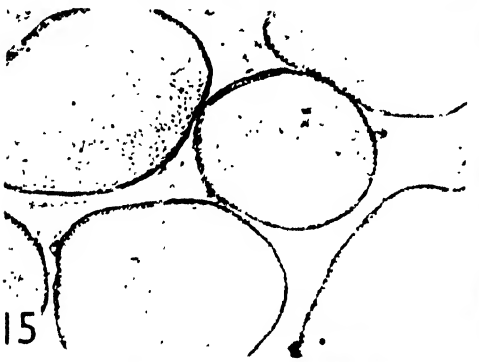
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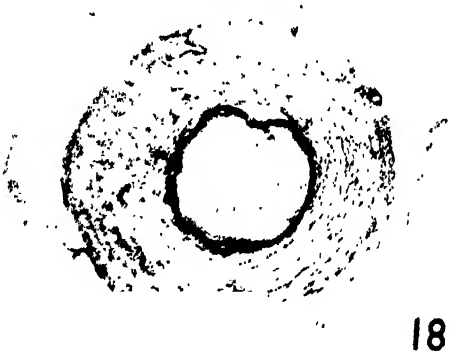
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Diethylstilbestrol treatment: The nucleus of the epithelial cells shows intense phosphatase activity but in other components the reactions are more or less similar as in the estradiol dipropionate-treated animals.

Gonadotrophic hormone treatment: The epithelial cells alone show very faint reactions for the enzyme but the other components are entirely negative for the phosphatase.

Discussion.

Our results on the distribution of alkaline phosphatase in the testis and the genital accessories of the guineapig are found to differ in several respects from those reported by the previous authors. Thus, Bern (1949) and Gomori (1941) obtained negative reactions for the enzyme in the interstitial stroma of the testis. We, however, observed phosphatase activity in the nucleus of the Leydig cells and in the endothelium of the interstitial capillaries. According to Bourne (1943) the seminal vesicles are totally devoid of enzyme activity. Bern also noted very faint reactions only in the fibro-muscular wall of the organ. In contrast, we observed intense phosphatase activity in the fibro-muscular wall of the seminal vesicles of this species. The last-named author also reported the epididymal epithelium to be negative for the enzyme but we have unmistakable evidence of strong nuclear phosphatase activity in the epithelium of the same organ. Our findings on the distribution of the enzyme in the vas deferens are practically in agreement with those of Bern and Bourne but differ markedly from those of Zorzoli and Stowell (1947) who demonstrated pronounced phosphatase activity in the nuclei of the mucosal epithelium. It appears probable that these differences in the location and distribution of the enzyme are due to the different periods of incubation employed by the various authors. It is, however, interesting to note in this connection that the picture of phosphatase distribution seen in the guineapig's testis is comparable in every way with that in the adult pigeon (Kar, 1951*b*).

The hormonal treatments caused considerable loss of testicular phosphatase activity in the guineapig, but among the different hormones used in this study the effects of progesterone and diethylstilbestrol were less severe in this respect than the rest, since appreciable amounts of the enzyme were clearly discernible in some components of the testis. The other hormones in our list inhibited phosphatase activity to such an extent that practically no trace of the enzyme was visible in our preparations. It has recently been reported that DCA inactivates phosphatase activity in the testis of sparrows (Kar, 1951*a*) and likewise responses are also elicited in the pigeon's testis by the gonadal hormones (Kar, 1951*b*). If we reckon these findings against those made in this study, we find that the action of these hormones in the two species of vertebrates studied by us are strikingly similar.

The enzymatic response in the genital accessories of the guineapig to steroid hormones brings to light some interesting facts. Thus, testosterone propionate caused a reduction in phosphatase activity in all the accessory organs but DCA exerted no influence whatsoever on epididymis and vas deferens, although the enzyme activity in the seminal vesicles and the prostate was inhibited to a marked extent. Progesterone resembled the corticoid in modifying the phosphatase activity in all the organs but estradiol dipropionate augmented enzyme activity in the prostate and in the vas deferens. However, the ovarian hormone considerably depressed phosphatase activity in the seminal vesicles and did not alter the enzymatic picture of the epididymis. The action of diethylstilbestrol was practically in line with that of the other estrogen, whereas gonadotrophic hormone differed from the steroid hormones in that it failed to evoke any enzymatic response in the accessory genitalia of our material.

It will be evident from the above that of all the hormones used in this study the androgen alone had uniform effects on phosphatase activity of the genital accessories. Now, viewing the situation from a slightly different angle we find

that the actions of DCA and progesterone on enzyme activity in the accessories were remarkably alike and the same was also the case with the estrogens. On two identical influences on the adreno-cortical phosphatase activities in the guineapig and the pigeon (Kar and Ghosh, 1952; Kar, 1951*a*). We had further noticed that estradiol dipropionate and diethylstilbestrol consistently inactivated alkaline phosphatase in the guineapig's adrenal cortex (Kar and Ghosh, 1952). It is now well known that the chemical structure of the corticoid and the luteoid are great deal alike (Burrows, 1949). The two hormones also have some similarities in their physiological effects (Turner, 1948). On the other hand, the estrogens used by us have lesser chemical affinities but more of physiological likeness (Grollman, 1942). Our studies, therefore, clearly indicate that these hormones with close chemical or physiological similarities (or both) are also cytochemically alike.

Summary.

The cytochemical demonstration of alkaline phosphatase activity has been made in the male genital system of the guineapig. Steroid hormones like testosterone propionate, DCA, estradiol dipropionate and the non-steroid gonadotrophic hormone considerably inhibited testicular phosphatase activity, but the effects of progesterone and diethylstilbestrol were less striking in this respect. The phosphatase in the accessory genital organs responded uniformly to androgen but the effects of other steroid hormones were somewhat variable. The gonadotrophic hormone, however, failed to evoke any enzymatic response in the accessory genitalia. The remarkable cytochemical likeness between some hormones is pointed out.

Acknowledgments.

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Explanation of Plate VII.

(*All figures are photomicrographs and are magnified* ×30.)

1. Section through the testis of a control guineapig showing alkaline phosphatase activity.
2. Section through the testis of an androgen-treated guineapig. Note the disappearance of the enzyme.
3. Section through the testis of DCA-treated guineapig. The loss of phosphatase activity is comparatively less than in fig. 2.
4. Section through the testis of a progesterone-treated guineapig. Compare with figs. 2 and 3.
5. Section through the testis of a diethylstilbestrol-treated guineapig. Note the continuation of enzyme activity in some tubular components.
6. Section through the testis of a gonadotrophic hormone treated guineapig. Note the absence of phosphatase activity.

Explanation of Plate VIII.

(*All figures are photomicrographs and are magnified* ×30.)

7. Section through the seminal vesicle of a control guineapig. Note pronounced phosphatase activity in the mucosal pleats.
8. Section through the seminal vesicle of an androgen-treated guineapig. Note the reduction of enzyme activity from the mucosa.
9. Section through the seminal vesicle of a DCA-treated guineapig.
10. Section through the seminal vesicle of a diethylstilbestrol treated guineapig. Note the presence of phosphatase activity in the fibro-muscular stroma and in the sub-epithelial region.
11. Section through the prostate of a control guineapig. The phosphatase activity is negligible.
12. Section through the prostate of an estradiol dipropionate-treated guineapig. Note the presence of the enzyme in the mucosa.

Explanation of Plate IX.

(*All figures are photomicrographs and are magnified* ×30.)

13. Section through the prostate of a diethylstilbestrol-treated guineapig.
14. Section through the epididymis of a control guineapig. Note the marked phosphatase activity in the basement membrane of the tube.
15. Section through the epididymis of an androgen-treated guineapig. Note the loss of phosphatase activity.
16. Section through the epididymis of diethylstilbestrol-treated guineapig.
17. Section through the vas deferens of a control guineapig.
18. Section through the vas deferens of an estradiol-treated guineapig. Note the presence of pronounced enzyme activity in the sub-epithelial stroma.

FURTHER OBSERVATIONS ON DIRECTIONAL CHANGES IN LOCUSTS AND OTHER SHORT-HORNED GRASSHOPPERS (INSECTA: ORTHOPTERA: ACRIDIDAE), AND THE IMPORTANCE OF THE THIRD INSTAR.

(With one Text-figure.)

By M. L. Roonwal, *M.Sc., Ph.D. (Cantab.), F.N.I., F.Z.S.I.*,
Forest Entomologist, Forest Research Institute, Dehra Dun.

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I—Introduction.

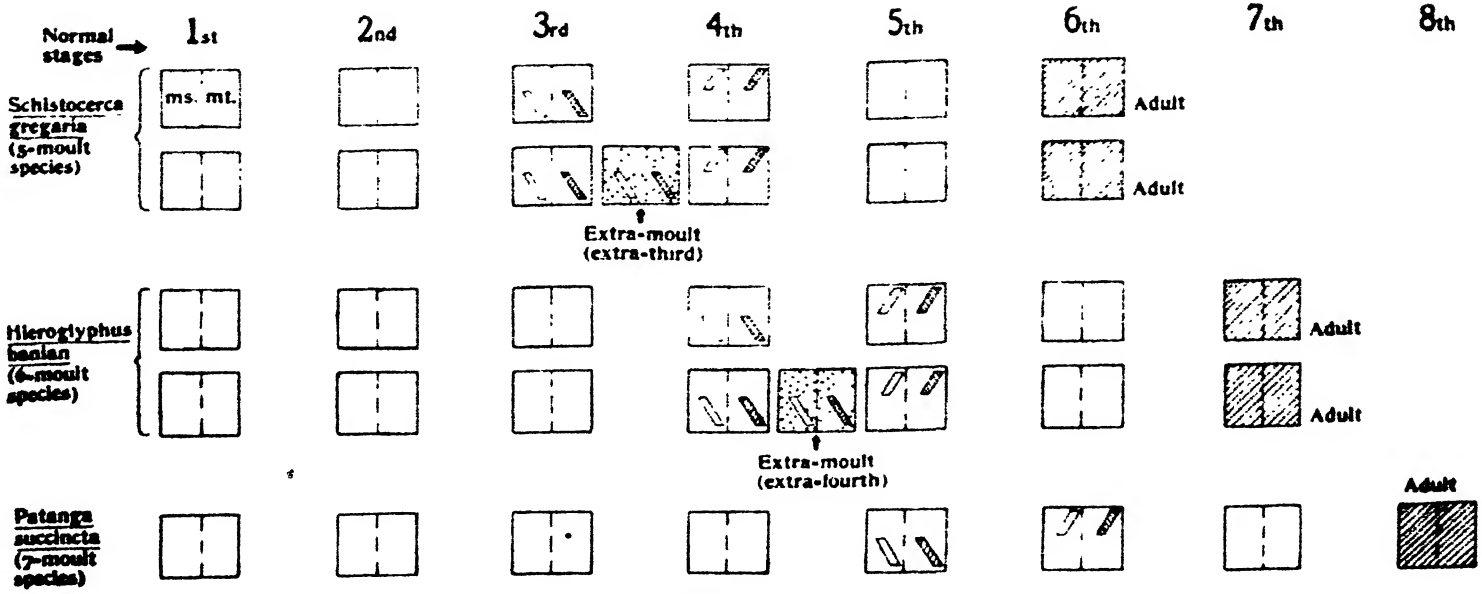
It was shown some years ago (Roonwal, 1938, 1940) that locusts and other short-horned grasshoppers (Orthoptera: family Acrididae) undergo in or about the third instar a series of extraordinary changes in respect of morphological, behaviouristic and physiological conditions, often resulting in a peculiar 'directional reversal'. As these changes are centred around the third instar hopper in the 5-moult species, the exceptional importance of that instar in the life-history of these grasshoppers was emphasised. The number of moults (excluding the 'intermediate moult') and the normal number of nymphal instars in the Acrididae varies from 4 to 7 depending upon the species (see Roonwal, 1946), but 5 is the most common number.

In the present paper I have discussed the new material assembled during the last 10 years, which has a bearing on the subject of directional reversal and the importance of the third or middle instar. In particular, I have discussed the data of Webley (1951) on the blood-cell counts, and of myself (Roonwal, 1946, 1947) on eye-stripes and extra-moulting in relation to the reversal of the elytron-wing complex. Some new data on the number of antennal segments are also discussed.

As a result of this new information, the importance of the third instar has been confirmed. As Webley (1951, p. 35) recently stated in discussing his work on blood-cell counts:

'Roonwal (1940) has shown the importance of the third instar in the Acrididae. The blood-cell counts of the present work give a further physiological indication of its importance.'

While it is now clear that great metabolic changes are taking place in the third instar, we are still far from understanding their biological significance, especially in regard to the directional changes.



TEXT-FIG. 1.

Diagrammatic representation of the meso- and metathoracic regions, in side-view, of the various post-embryonic developmental stages in the Acrididae, to show the chronological sequence of the upturning of the elytron- and wing-rudiments (directional reversal of the elytron-wing complex) and its relationship to the normal number of moults (5–7) in the species on the one hand, and to extra-moulting on the other. For the sake of simplicity, the elytron- and wing-rudiments are shown only in the stages when the upturning of the elytron-wing complex occurs. In the earlier stages the eltyron- and wing-rudiments (which first make their appearance in the second stage) point downwards, and in the later stages upwards.

Rule 2.—If in a species the total number of normal stages (including the adult, but excluding the vermiform larva) is t, then the chronological stage in which the directional reversal of the elytron-wing complex usually occurs is $t-2$; and, in accordance with Rule 1, the stage which usually represents the extra-instars (in individuals in which only one such instar occurs) is $[(t-2)-1]$.

Data available later have supported these rules. Thus, in the Moroccan Locust, *Dociostaurus maroccanus* (Thunb.), Jannone (1939) has reported 5 moults, and the reversal or upturning of the elytron-wing complex occurs at the third moult, *i.e.*, when hoppers moult from the third into the fourth stage, as in *Schistocerca gregaria*. Again, in *Hieroglyphus nigrorepletus* (Bol.) recently studied by me (Roonwal, 1952, in press), the number of moults is 6, and the directional reversal of the elytron-wing complex occurs in the fifth stage.

A generalised diagram illustrating Rule 2 is given in Text-fig. 1. The bearing of these rules on the importance of the third instar is discussed below (*vide* Discussion and Conclusions).

The limited correlation which exists between extra-moulting and the number of eye-stripes added during post-embryonic development has been discussed below. Here it needs only to be emphasised that the third instar is exceptional both in normal and extra-moulting forms in the 5-moult species. The same is true, to a certain extent, with regard to the antennal segments (*vide* below).

3. *Eye-stripes, dorsal spot of eye and antennal segments.*

(i) *Eye-stripes.*

It is now well known that the Desert Locust, *Schistocerca gregaria* (Forskål), possesses brownish, vertical eye-stripes which in the *gregaria* phase individuals are partly obscured owing to the heavy development of dark pigment in the inter-stripe region. Roonwal (1936) has shown that the *solitaria* phase individuals are of two types, *viz.*, 6- and 7-eye-striped. A study of the post-embryonic development of the eye-stripes has shown (Roonwal, 1937, 1947) the existence of features which are of interest for our present discussion. Basically, the development runs along the following pattern:—There is no stripe in the freshly emerged first instar hopper, but one develops later in that instar. With every subsequent moult a stripe is added so that there are 2 stripes in the second, 3 in the third, 4 in the fourth, 5 in the fifth, and 6 in the sixth (or adult) stages. This pattern occurs in the 6-eye-striped individuals which undergo the normal number of 5 moults. In the 7-eye-striped individuals, the one-moult-one-stripe relationship holds good in most stages, but the extra seventh stripe is produced in two ways (Roonwal, 1937, 1947): (i) by the addition of *two* stripes at the second moult (*i.e.*, the third stage hopper has *four* stripes instead of the normal three); and (ii) by the interposition of an extra-moult in the third stage (and rarely in the fourth) during which a new eye-stripe is added (stripe-positive extra-moult). But extra-moulting does not necessarily lead to the addition of a stripe; stripe-neutral extra-moults occasionally take place.

The third instar is exceptional in two respects, *viz.*, (i) that in about one-half to three-quarters of the 7-eye-striped individuals, the extra or seventh stripe (as compared to 6-striped individuals) is produced by the addition of a stripe-positive extra-moult usually in the third stage; (ii) in the remainder of the 7-striped individuals, the third stage hopper possesses four, instead of the usual three eye-stripes, the extra stripe being added without the intervention of an extra-moult.

(ii) *Dorsal spot of eye.*

At the dorsal end of the compound eyes in the Desert Locust, *Schistocerca gregaria* (Forskål), and several other (probably all) Acrididae, there lies, nearer the posterior than the anterior side, a small dark chocolate-coloured area shaped

somewhat like the head of a hammer, with the base pointing towards the anterior side and the narrower end towards the posterior (Roonwal, 1947, pp. 248-249, Figs. 1 and 2). This has been termed the *dorsal spot* by Roonwal (1936).. Its post-embryonic development has been studied by Roonwal (1947, p. 256). In the freshly-hatched first stage hopper the base of this sub-triangular hammer-shaped dorsal spot points posteriorly, a condition which is maintained in the second and third stages. When the hopper moults from the third into the fourth stage, there is a *directional reversal* of the base which now points antero-dorsally. The new orientation is maintained in the fifth stage and the adult.

This directional reversal of the dorsal spot of the eye is comparable to the similar reversal of the elytron-wing complex occurring in the same stage, and emphasises the importance of the third instar.

(iii) *Antennal segments.*

It is well known that the number of antennal segments in the Acrididae increases during post embryonic development from about 8–14 in the first stage hopper to about 25–30 in the adult.

In *Schistocerca gregaria* (Rao, 1938; Mukerji and Batra, 1938) there are 13 antennal segments in the first stage hopper, 19 in the second stage, 20-21 in the third, 22-23 in the fourth, 24-25 in the fifth, and finally 26-27 in the sixth or adult stage with 6 eye-stripes. In the 7-eye-striped adults the number is 27–29, in the 8 striped adults 30, and in the 5-striped adults 25, the increase or decrease in the number being explicable to a certain extent by extra-moulting and under-moulting respectively. It will be noticed, as has already been pointed out by me (Roonwal, 1947, p. 255, foot-note), that, as in the case of the eye-stripes, the second moult and the resulting third stage here also are exceptional. Two kinds of individuals are produced in the third stage: one with 20 and another with 21 antennal segments. This condition applies alike to the 6- and 7-eye-striped individuals, although ultimately the 7-eye-striped adults possess more antennal segments than 6-striped ones, this excess resulting from additions made later as a result of an extra-moult.

In *Hieroglyphus nigrorepletus* Bol. (Roonwal, 1952, in press) the increase in the number of antennal segments in the various stages occurs as follows:—I, 13; II, 14; III, 18-20 (rarely 16-20); IV, 21-23 (mostly 21, and rarely 16); V, 23–25 (mostly 23, rarely 20); VI, 26-27 (rarely 14–29); and VII (adult), 27-28 (rarely 20-29) Here again, as in *Schistocerca gregaria*, the first intra-instar difference appears in the third instar. Another feature noticed is the occurrence of bilateral asymmetry in the right and left antennae of the same individual, the difference in the number of antennal segments being as high as 14 in some cases. It is interesting that the bilateral asymmetry also is first evident in the third stage and continues thereafter.

It should, however, be pointed out that not in all the Acrididae is the intra-instar difference first discernible in the third instar, for, according to Uvarov (1928, p. 45, Table), this difference may arise even in the second instar and rarely in the first (see discussion in Roonwal, 1952).

III—Discussion and Conclusions.

It will be seen from the data on extra-moulting and the directional reversal of the elytron-wing complex (E-W complex, for brevity) that, so far as the 5-moult individuals of all the species thus far studied are concerned, the extra-moulting occurs in the stage immediately following the normal third. As the majority of the Acrididae so far studied are of the 5-moult kind, we may state that in these forms the extra-moulting and the directional reversal of the E-W complex occurs in the *middle* hopper instar, a description, however, which does not apply

to the remaining Acrididae. It will be seen from my Rule 2 discussed above and Text-fig. 1 that the numerical factor of two instars always following the instar in which the directional reversal of the E-W complex occurs would appear to represent the position more generally. Both the present writer (Roonwal, 1938, 1940, 1946, 1947, and the present paper) and Webley (1951) have discussed the importance of the third instar, and this is quite clear in the 5-moult species. In the other species, however, Rules 1 and 2, which were formulated to generalise the position regarding extra-moulting and the direction reversal of the E-W complex, represent the true position. No comparative data are yet available to enable us to decide whether these two rules also apply to other metabolic activities, *e.g.*, variation in blood-cell counts, respiratory rates, etc.; data regarding these activities are hitherto available for the 5-moult species only.

We may now conclude, on the evidence discussed above, that at any rate in the 5-moulting species of Acrididae—which is by far the most common condition—the third instar is of exceptional importance from the point of view of metabolic activity, as some striking changes occur either during that instar or in the immediately preceding or immediately following periods. In many of these changes a directional reversal occurs either in a morphological structure or a physiological process or a behaviouristic pattern. The hitherto known processes of this kind are listed below under three categories. (For fuller details of these examples, see Roonwal, 1940, and the preceding pages of the present account. Except where otherwise stated, the data apply, as a rule, to the 5-moult species.)

List of the hitherto known changes.

(*a*) *Morphological changes.*

1. The upturning of the elytron- and wing-rudiments (which has been termed as the directional reversal of the elytron-wing complex) occurs immediately after the third stage (*i.e.*, at the third moult). This applies to the 5-moult species only; in the rarer 6- and 7-moult species, the chronological position of this reversal is governed by Rule 2 of Roonwal (1946), already discussed above.

2. The growth coefficients in the 5-moult species increase towards the third stage when they are highest, and thereafter decline. In the 4-moult species also this reversal occurs in the third stage, but in the opposite direction.

3. The number of eye-stripes added is normally one in each stage, but *two* are added in the third stage in some forms.

4. The dorsal spot of the eyes undergoes directional reversal in its disposition immediately after the third stage, a feature which is closely comparable to the directional reversal of the elytron-wing complex.

5. The number of antennal segments increases from 8–13 in the first stage to 25–30 in the adult. In the first two hopper stages there is usually a constant number for all the individuals of a species, and intra-instar difference in numbers first arises in the third stage although sometimes also in the second and even in the first.

(*b*) *Behaviouristic changes.*

6. In the reaction to humidity, as regards locomotory activities, hoppers of the third and following stages behave differently from those of the first and second stages.

7. The 'activity figure' of the hoppers shows a directional reversal. It falls up to the third stage, but rises again in the fourth, the rise being maintained in the fifth.

(c) Physiological changes.

8. The respiratory metabolism decreases up to the third instar, and increases from the fourth instar onwards.

9. In the 5-moult species, an extra-moult occurs mostly in the third stage and only rarely in the second and fourth. In the rarer 6-moult species, Rule 2 of Roonwal (1946), as already discussed above, holds good.

10. In the 5-moult species, the relative increase in the number of blood-cells (as well as their absolute numbers in one case) per unit volume of blood in the hopper stages is the greatest in the third stage, and declines thereafter.

IV—Summary.

1. Since the subject of directional reversal of certain morphological, behaviouristic and physiological processes in the Acrididae and the importance of the third instar was first opened by the writer (Roonwal, 1938, 1940), many new facts which have a bearing on the subject have been assembled. These new facts are discussed here.

2. In *Locusta migratoria migratorioides* there is, in the third instar hopper, a great increase, both relatively and in absolute numbers, in the number of blood-cells per unit volume (Webley, 1951). A similar increase in relative numbers also occurs in *Schistocerca gregaria* (Mathur and Soni, 1937).

3. In the 5-moult species, extra-moulting occurs as a rule in the third stage (Roonwal, 1946, 1947). The chronological relationship in the rarer 6- and 7-moult species is somewhat different and Rules 1 and 2 of Roonwal (1946) are obeyed.

4. In *Schistocerca gregaria* the third instar is exceptional in the addition of two eye-stripes, instead of the normal one, in some of the 7-eye-striped forms. In that same species, the directional reversal of the dorsal spot of the eyes occurs immediately after the third stage.

5. In the increase in the number of antennal segments during post-embryonic growth, the third instar is exceptional in the fact that the intra-instar differences as well as bilateral asymmetry are first evident most commonly in the third instar.

6. The correlation between extra-moulting and the upturning of the elytron-wing complex is discussed.

7. A list is given of the hitherto known instances of directional reversal and the importance of the third instar.

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VARIATION AND POST-EMBRYONIC GROWTH IN THE NUMBER OF ANTENNAL SEGMENTS IN THE *PHADKA* GRASSHOPPER (*HIEROGLYPHUS NIGROREPLETUS* BOLIVAR), WITH REMARKS ON THE DESERT LOCUST AND OTHER ACRIDIDAE (INSECTA: ORTHOPTERA).

(With 10 Tables and 2 Text-figures.)

By M. L. ROONWAL, *M.Sc., Ph.D. (Cantab.), F.N.I., F.Z.S.I., Forest Entomologist, Forest Research Institute, Dehra Dun.*

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I—INTRODUCTION.

Data on variation and post-embryonic growth in the number of antennal segments in the family Acrididae (locusts and short-horned grasshoppers) are scattered in literature. The earlier data were summarised by Uvarov (1928), but a considerable amount of new and more detailed information has accumulated subsequently.

Here I have presented first, the new data on variation and post-embryonic growth in the number of antennal segments in the *phadka* grasshopper, *Hieroglyphus nigrorepletus* Bolivar, whose egg-pods were obtained by me in June 1950 from the Ajmer State in Rajasthan, and subsequently reared in the Insectary at the Forest Research Institute. A large number of adults and hoppers of all stages were examined. Secondly, I have critically discussed the available data on the Desert Locust, *Schistocerca gregaria* (Forskål), and added some new data on that species. Finally, the available information on the family Acrididae as a whole is summarised and discussed, and some general tentative conclusions arrived at. There is need for more detailed data on this subject, and it is hoped that this may be forthcoming in the future. A general discussion on the growth of the antennal segments in various orders of insects will be found in Imms (1940).

Acknowledgment is made of the assistance received from Mr. Balwant Singh, Research Assistant (I) in the Forest Entomology Branch, in counting the number of antennal segments of *Hieroglyphus nigrorepletus*.

II—ANTENNAE OF *Hieroglyphus nigrorepletus* BOLIVAR.

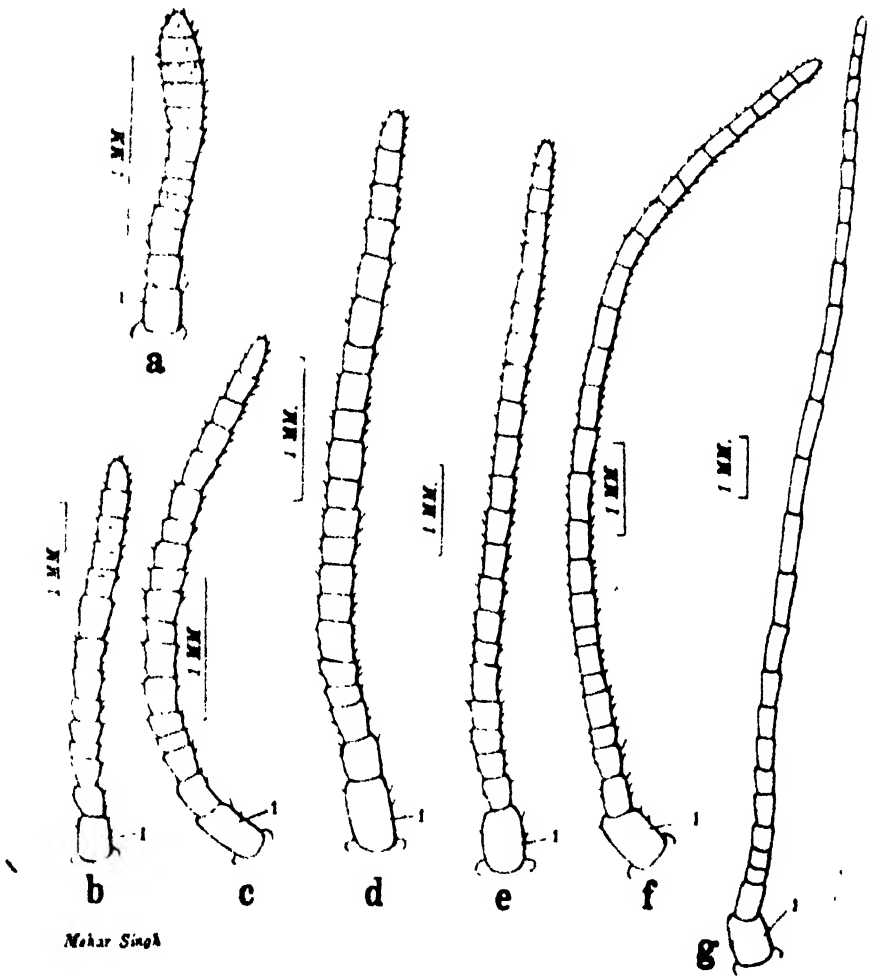
(Text-fig. 1 and Tables 1–3.)

(i) *Post-embryonic growth.*

A careful count of the number of antennal segments was made in all the 6 hopper stages and in the "fawn type' and 'green type' brachypterous (short-winged)

adults of *Hieroglyphus nigrorepletus* Bol., a maximum of 13 individuals being examined for each stage.* In addition, one example of the rare macropterous (long-winged) adult was also examined. The number in the right and left antennae was counted separately, but no significant differences were found, though the number frequently varies in the same individual. The sexes were analysed separately, but no constant sexual differences were noticeable. The number of antennal segments (Table 1) increases from 13 in the first stage hopper to a maximum of 29 in the seventh or adult stage, the number present in each stage showing a certain amount of variation as discussed below.

In the first and second stages the number is 13 and 14 respectively, though in some individuals of the latter stage the 7th, 8th and 9th segments show some signs



TEXT-FIG. 1.

Hieroglyphus nigrorepletus Bolivar. Antennae of various instars. (*a*) First instar, left antenna of ♂, with 13 segments. (*b*) Second instar, right antenna of ♂, with 14 segments. (*c*) Third instar, left antenna of ♀, with 18 segments. (*d*) Fourth instar, right antenna of ♂, with 21 segments. (*e*) Fifth instar, right antenna of ♀, with 24 segments. (*f*) Sixth instar, left antenna of ♀, with 26 segments. (*g*) Seventh instar (adult), right antenna of brachypterous (short-winged) ♀, with 27 segments.

1, first (basal) segment or scape.

* In this paper the terms 'stage' and 'instar' are used as synonyms.

of partial division into two segments so as to give the impression of a total of 17 segments. In the third stage the intra-instar variability (*i.e.*, variation between the different individuals of the same instar) is first discernible* and continues in the subsequent instars. The number of segments in the third stage varies from 16–20, but ranges mostly around 18–20. In the fourth stage, the number is usually 21–23 (most commonly 21), but in one female the left antenna had only 16 segments, although the right antenna had 21. In the fifth stage the number is usually 23–25 (most commonly 23), but in one male the right antenna had only 20 segments, although the left one had 23. In the sixth stage the number is usually 26-27, and occasionally as high as 28. At the lower end, numbers as low as 14-19 occasionally occur in the sixth stage on one side of an individual, although the number on the other side of that same individual may be normal; this extreme irregularity appears to be rather more common in females than in males, as the following four counts of females show (see Table 1 for males), the number within brackets being the number on the opposite side of the same individual: 19(26); 16(–); 14(28); 14(27). In the seventh stage (brachypterous adults) the number is commonly 27-28, occasionally 29; rarely, it may be as low as 20–22 on one side, although the number on the opposite side of the same individual is the normal 27-28. In one adult female the number was 20 in the right and 28 in the left, the right antenna showing signs of damage though the tip was rounded. Similarly, in one male the left antenna, which appeared quite normal, had 20 segments, and the right one 28. No significant difference between the 'fawn' and 'green' type adults was noticeable. One macropterous adult male had 28 segments in both the antennae.

Summing up, the post-embryonic growth in the number of antennal segments is as indicated in Table 2 below:

TABLE 2.

Hieroglyphus nigrorepletus Bol. Summary of the post-embryonic growth in the number of antennal segments.

Stage.	I	II	III	IV	V	VI	VII (adult).
Number of antennal segments.	13	14	Usually 18–20. Rarely 16-17.	Usually 21-23 (mostly 21). Rarely as low as 16.	Usually 23-25 (mostly 23). Rarely as low as 20.	Usually 26–27. Rarely as low as 14-19 and as high as 29.	Usually 27-28. Rarely as low as 20–22 and as high as 29.

It will thus be seen that the number of antennal segments alone is not always a safe guide in determining the hopper stage, although it does provide a useful guide when considered with other characters.

For comparison, it is interesting to note that in the closely allied species *Hieroglyphus banian* Fabr. (where males undergo 6 moults and females 7, in contrast to 6 moults in both the sexes in *H. nigrorepletus*), the post-embryonic increase in the number of antennal segments in the various stages, according to the data of Coleman and Kuhni Kannan (1911), is from 13 in the first stage in both sexes to 25-26 in the sixth (or penultimate) stage in males and 27-28 in the seventh (or penultimate) stage in females (Table 1). Figures for adults were not given by

* Attention to this phenomenon and to the importance of the third instar in the family Acrididae in general has already been called by Roonwal (1946; 1952).

these authors. All the 8 long-winged adults (4 males, 4 females) from Ceylon, that I recently studied, had 29 segments

(ii) *Variation.*

Variation in the number of antennal segments has to be considered in three respects: (*a*) the occurrence of normal variability as between the different instars (intra-instar variability); (*b*) the occurrence of bilateral asymmetry in the right and left antenna of the same individual; and (*c*) the variation in the increase in the number of segments at each moult.

The normal intra-instar variability has already been considered above to some extent. Regarding the occurrence of bilateral asymmetry, it will be noticed that in the first and second instar hoppers there is complete symmetry, the number in the right and left antennae being 13 in the first and 14 in the second stage in all the individuals examined. The intra-instar difference (Table 1) as well as bilateral asymmetry (Table 3) in the right and left antennae of the same individual are first

TABLE 3.

Hieroglyphus nigrorepletus Bol. Data on bilateral asymmetry (difference between the right and left antenna of the same individual) in the number of antennal segments. (*From* data in Table 1.)

Abbreviation.—T., total.

Stage.	Total number examined.	Number of individuals showing *symmetry* (and % of total).	Number of individuals showing *asymmetry* (and % of total).	Difference in the number of antennal segments in *asymmetrical* individuals.	
				Range.	Frequency distribution of differences. (Figures in brackets indicate frequency.)
I	13	All (100%)	Nil	.	..
II	♂ 8 ♀ 11	All (100%)	Nil	..	..
III	♂ 10	6(60%)	4(40%)	1 - 2	1, 1, 1, 2
	♀ 10	2(20%)	8(80%)	1 2	1, 1, 1, 1, 1, 2, 2, 2
	T.20	8(40%)	12(60%)	1 - 2	1(8), 2(4)
IV	♂ 13	12(92·3%)	1(7·7%)	1	1
	♀ 13	10(76·9%)	3(23·1%)	1- 5	1, 1, 5
	T.26	22(84·6%)	4(15·4%)	1- 5	1(3), 5(1)
V	♂ 11	6(54·5%)	5(45·5%)	1- 3	1, 1, 1, 2, 3
	♀ 8	4(50%)	4(50%)	1	1, 1, 1, 1
	T.19	10(52·6%)	9(47·4%)	1- 3	1(7), 2(1) 3(1)
VI	♂ 6	4(66·7%)	2(33·3%)	1- 3	1, 3
	♀ 10	4(40%)	6(60%)	1-14	1, 1, 3, 7, 13, 14
	T.16	8(50%)	8(50%)	1-14	1(3), 3(2), 7(1), 13(1), 14(1)
VII (adult)	♂ 13	5(38·5%)	8(61·5%)	1- 8	1, 1, 1, 1, 1, 2, 7, 8
	♀ 14	9(64·3%)	5(35·7%)	1- 8	1, 2, 6, 8, 8
	T.27	14(51·9%)	13(48·1%)	1- 8	1(6), 2(2), 6(1), 7(1), 8(3)

evident in the third stage (*vide* remarks in foot-note above), and continue thereafter up to the seventh or adult stage. In nearly all the stages from the third to the adult, roughly one-half the number of individuals are symmetrical, and the remainder

asymmetrical. As regards the difference in the number of segments in the right and left antennae of the same individual, this varies from 1-2 in the third stage, 1–1·4 in the sixth, and 1–8 in the seventh (adult). On the whole, there is a rough tendency for this difference to increase with growth, the range of the difference being rather higher in the older instars. There is also noticeable a slight tendency for this difference to be more marked in females than in males, this feature being especially noticeable in the sixth and seventh stages.

The increase in the number of segments is 1 at the first moult and 2–6 at the second. In subsequent moults the increase in individual isolated hoppers was not followed, so that it is not possible to state the precise increase in number of segments with each moult from individual cases.

III—Antennae of *Schistocerca gregaria* (Forskål).

(Text-fig. 2 and Tables 4–9.)

Variation in the number of antennal segments in *Schistocerca gregaria* will be considered from two aspects, namely: (*i*) variation in the number of segments in the adult and its correlation with the number of eye-stripes, phase-categories and the number of moults; and (*ii*) the post-embryonic growth and variation in the number of segments.

I have here critically discussed the available data, and also added some new facts.

(i) *Variation in the adults.*

Ballard, Mistikawi and Zoheiry (1932) stated that both in the *solitaria* and the *gregaria* phases in *Schistocerca gregaria* the number of antennal segments in individuals undergoing the normal 5-moult (*i.e.*, 6-stage, including the adult) cycle increased from 13 in the first stage to 19 in the second, 21 in the third, 23 in the fourth and 25 in the fifth. No mention was made of their correlation with the variation in the number of eye-stripes which was discovered later (Roonwal, 1936–1947). We now know firstly, that the number of eye-stripes vary from 5 to 8, but are mostly 6 to 7; and secondly, that phase *gregaria* individuals always have 6 eye-stripes whereas phase *solitaria* individuals have either 6 to 7 eye-stripes.

Husain (1937) claimed that 7-eye-striped adults invariably possess 28 antennal segments. He also claimed a correlation of this number with the occurrence of an extra-moult in the 7-eye-striped individuals. Both these claims have not been borne out by subsequent work.

Rao (1938), and Mukerji and Batra (1938) gave the correlation of antennal segments and eye-stripes in the adults as follows:—5-striped, 25; 6-striped, 26–27; 7-striped, 28–29; and 8-striped, 30.

Rao and Gupta (1939) showed that 6-eye-striped phase *gregaria* individuals (taken from swarms) have 26 segments, while 6-eye-striped phase *solitaria* individuals have 27 segments. I have been able to confirm the first part of this finding. The second part, however, is only partially correct. I have examined a number of phase *solitaria* 6-eye-striped individuals (Table 4) and found in this category individuals with both 26- and 27-segmented antennae, as also found by Rao and Gupta. But a further analysis has shown that *solitaria* individuals with higher E/F ratios (length of elytron/length of hind-femur) tend to have 26 segments, while those with lower E/F ratios have generally 27 segments in the antennae, as is evident from the following summary of the data in Table 4:—

(*a*) *Among males*—

(i) E/F 1·88–2·00.—Out of 15 examples, 1 had 26, and 14 had 27 segments.
(ii) E/F 2·01–2·05.—Out of 12 examples, 7 had 26, and 5 had 27 segments.
(iii) E/F 2·06–2·20.—All the 5 examples examined had 26 segments.

TABLE 4.

Schistocerca gregaria (Forskål). Number of antennal segments in 6-eye-striped phase *solitaria* individuals, taken from Baluchistan in 1936-37 under typical *solitaria* conditions of very low population of usually below 1,000 per square mile. Note correlation with E/F ratio.

Serial No.	Sex.	E/F ratio.	No. of antennal segments.	Serial No.	Sex.	E/F ratio.	No. of antennal segments.
1	♂	1·88	27	26	♂	2·05	26
2	♂	1·88	27	27	♂	2·05	26
3	♂	1·89	27	28	♂	2·06	26
4	♂	1·89	27	29	♂	2·14	26
5	♂	1·89	27	30	♂	2·15	26
6	♂	1·90	27	31	♂	2·17	26
7	♂	1·92	27	32	♂	2·20	26
8	♂	1·92	27				
9	♂	1·96	26	33	♀	1·97	27
10	♂	1·96	27	34	♀	1·97	27
11	♂	1·98	27	35	♀	2·02	27
12	♂	1·99	27	36	♀	2·02	27
13	♂	1·99	27	37	♀	2·05	27
14	♂	1·99	27	38	♀	2·05	26
15	♂	2·00	27	39	♀	2·05	27
16	♂	2·01	26	40	♀	2·09	27
17	♂	2·01	27	41	♀	2·14	27
18	♂	2·01	27	42	♀	2·14	27
19	♂	2·01	26	43	♀	2·14	27
20	♂	2·01	26	44	♀	2·16	26
21	♂	2·02	27	45	♀	2·16	26
22	♂	2·02	26	46	♀	2·17	27
23	♂	2·03	27	47	♀	2·20	26
24	♂	2·04	27	48	♀	2·23	26
25	♂	2·05	26	49	♀	2·24	26

(*b*) *Among females*—

(i) E/F 1·97–2·14.—Out of 11 examples, 1 had 26 segments, and 10 had 27 segments.

(ii) E/F 2·16–2·24.—Out of 6 examples, 5 had 26 segments and 1 had 27 segments.

The correlation between the number of adult antennal segments on the one hand and the number of eye-stripes and phase-category on the other, is briefly summarised in Table 5.

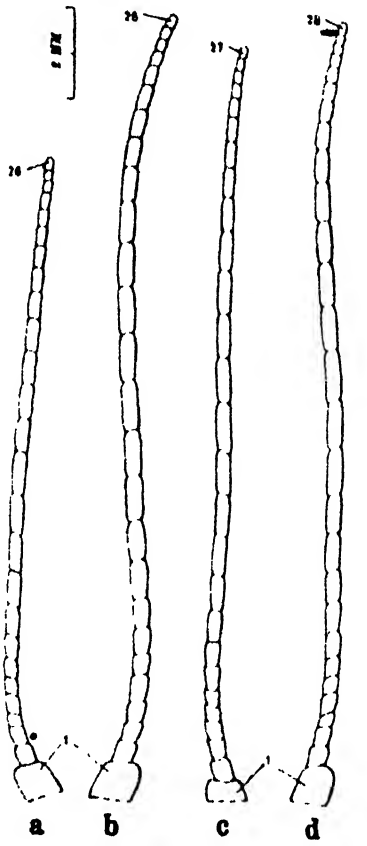
TABLE 5.

Schistocerca gregaria (Forskål). Correlation between the number of adult antennal segments on the one hand, and the number of eye-stripes and phase phase-category on the other.

Number of eye-stripes.	5 (rare).	6	7	8 (rare).
Number of antennal segments.	25	(i) Ph. *greg.*—26. (ii) Ph. *sol.*—26–27. 26 in those with higher E/F ratios and 27 in those with lower ratios.	28–29 (ph. *sol.*)	30
Normal number of moults.	4	5	5-6	6–7

(ii) *Post-embryonic growth.*

Regarding the mode of origin of the difference in the number of segments in the adult, a study of development has shown (Ballard, Mistikawi and Zoheiry, 1932; Rao, 1938; Mukerji and Batra, 1938; and Roonwal, present account) that the number



TEXT-FIGURE 2.

Schistocerca gregaria (Forskål). Antennae of adults showing variation in the number of segments. (*a*) Right antenna, with 26 segments, of a 6-eye-striped, phase *gregaria* ♀ from a swarm in Peshawar (N.W.F.P.). (*b*) Left antenna, with 26 segments, of a 6-eye-striped phase *solitaria* ♀ from Lasbela State, Baluchistan. (*c*) Right antenna, with 27 segments, of a 6-eye-striped phase *solitaria* ♀ from Lasbela State, Baluchistan. (*d*) Left antenna, with 28 segments, of a 7-eye-striped phase *solitaria* ♀ from Baluchistan.

1, first (basal) segment or scape; 26, 27, 28, twenty-sixth, twenty-seventh and twenty-eighth segments.

of antennal segments increases with each moult, the number in the first stage always being 13. Since extra-moulting is also *one* of the methods of the addition of extra eye-stripes (*vide* Roonwal, 1947), a certain degree of correlation between the increased number of eye-stripes and that of the antennal segments will be evident. On the other hand, individuals with the same number of eye-stripes, *viz.*, 6, may have a varying number of antennal segments, the number being partly correlated with phase-category but *not* to the number of moults, since 6-eye-striped individuals have, normally, 5 moults in *both* the *solitaria* and the *gregaria* phases. The statement of Mukerji and Batra (1938), that 'since the number of eye-stripes

have been found to correspond with the number of instars, and as the latter, in turn, bears a relationship with the number of antennal segments of each stage, it follows that the three factors are organically connected with one another', is only partially true, for the correlations claimed by these authors in respect of eye-stripes and moulting are only partial, as has already been shown by Roonwal (1947).

A study of post-embryonic development has shown that irrespective of the kind of adults produced in respect of eye-stripes and phase-category, *two* types of individuals are produced in the third instar hopper, one with 20 and another with 21 antennal segments. Thereafter, in eight 6-eye-striped examples studied, the course of subsequent development was common and 2 segments were added at each moult, thus resulting in 26- and 27-segmented adults (Table 6).

TABLE 6

Schistocerca gregaria (Forskål). Course of development of the antennal segments in 6-eye-striped individuals (all with 5-moults).

Stage.	I	II	III	IV	V	VI (adult)
Number of eye-stripes.	1	2	3	4	5	6
Number of antennal segments.	13	19	20	22	24	26
			21	23	25	27

The origin of the initial difference in the third stage is obscure, but it is not due to an extra-moult. It may be mentioned that this is yet another example of the peculiarity and extraordinary importance of the third instar (*vide* Roonwal 1940; 1952; and present paper, foot-note on p. 219 above). Nor is the difference in the number of moults *alone* the cause of the difference in the number of segments in the individuals with a varying number of eye-stripes as contended by Mukerji and Batra (1938), though moulting certainly is *one* of the factors which leads to the addition of segments. The number of segments is also partly correlated with phase-category in the 6-eye-striped individuals. The problem needs further enquiry.

IV—Discussion and General Conclusions.

(Tables 7–10.)

A study of the available data on variation in the number of antennal segments and their post-embryonic growth in the Acrididae shows that these features are distinguished by the following general characteristics:—

(i) The number of segments in the adult varies, with the species, from 17–30; variation within the species is confined to narrow limits not exceeding 1–2 as a rule.

The lowest adult numbers occur in *Poecilocerus pictus** (18) and in *Colemania sphenarioides* (17–19), and occasionally in *Hieroglyphus nigrorepletus* (as low as

* Four adults from India were examined by me and gave the following counts (R, right; L, left antenna):—♂ (R, 18; L, 18), ♂ (R, 18); ♀ (R, 18); ♀ (R, 18; L, 18).

20–22, though the usual number is 27–28). The highest numbers occur in *Hieroglyphus banian* (29), *H. nigrorepletus* (27–29), and a few (8-eye-striped) individuals of *Schistocerca gregaria* (30). Variation within a species is usually within narrow limits of 1–2; but in a few cases somewhat wider limits of variation are met with, as in *Hieroglyphus nigrorepletus* (1–9), the adult number in this species being 27–29, rarely as low as 20; and in *Schistocerca gregaria* (1–5), the adult number being 26–28, rarely 25–30.

(ii) During post-embryonic growth there is an increase* (by 1 or more segments at each moult) in the number of segments from an initially low figure in the first instar.

(iii) Generally speaking, since the number of segments increase with each moult, extra-moulting individuals (*i.e.*, individuals which undergo more moults than is normal for the species) tend to have more segments in the adult than the normal-moulting individuals; conversely, under-moulting individuals have fewer segments.

Thus, in *Melanoplus bivittatus* and *Schistocerca gregaria* the extra-moulting and under-moulting individuals have, generally, more and fewer segments respectively than the normal ones. On the other hand, in *Hieroglyphus banian* and *Colemania sphenarioides* the extra-moulting individuals have the same number of segments as the normal ones (Tables 1, 7 and 8).

(iv) The initial number of segments in the first instar hopper varies with the species from 8–14 (Tables 7 and 8).

This number is generally constant for the species, and variation within the species is uncommon. In a few cases, however, the number has been shown to be inconstant. Thus, in *Locusta migratoria* Linn. it varies from 13–14, and other numbers are also encountered rarely. In *Melanoplus mexicanus* Sauss. (= *M. atlantis* Ril.) it is 12, but in *M. spretus* (which is the supposed gregarious phase of *M. mexicanus*), it is 12–13. The number is lowest in *Poecilocerus pictus* and *Colemania sphenarioides*, in both of which it is 8, and highest in species of *Locusta*, *Schistocerca*, etc. (13–14).

(v) The number of segments in the adult is correlated to a certain extent, but not absolutely, with the initial number in the first instar, the adult number being generally higher in species with the higher initial number (Tables 7 and 8).

Thus, in *Poecilocerus* and *Colemania* the initial number is 8 and the final (adult) number 17–19; in *Phoetaliotes*, *Camnula* and *Dissosteira*, the initial number is 11, and the final number 23–24; in some species of *Melanoplus* the initial number is 12, and the final number 23–26; finally, in the remainder (*e.g.*, *Hieroglyphus*, *Schistocerca*, *Locusta*, etc.) the initial number is 13 (rarely 14), and the final number usually 26–29 and occasionally as low as 20–22 (some individuals of *Hieroglyphus nigrorepletus*) and as high as 29 (some individuals of *H. nigrorepletus*) and 30 (some individuals of *Schistocerca gregaria*).

(vi) Generally speaking, in a species the intra-instar variation (*i.e.*, variation between the different individuals of the same instar) first appears commonly in the third instar but sometimes also in the second (as in *Poecilocerus*, *Locusta* and *Dociostaurus*) (Table 7). Rarely, it is evident in the very first instar, as in *Melanoplus spretus* and in *Locusta migratoria migratoria*. Once it has made its appearance, the intra-instar variation is continued in the subsequent instars, though not in a regular way.

(vii) The increase in the number of segments with each moult in a species is generally constant (within narrow limits of variation), but varies from moult to moult, the number added generally, but not always, decreasing in the later moults as compared to the earlier (Tables 9 and 10).

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* For a general discussion on several orders of insects, see Imms (1940).

TABLE 7.

Number of antennal segments in each stage of a normal post-embryonic development in some Acrididae. *Abbreviation.*—Ad., adult.

* Species in which the number of antennal segments varies in extra- and under-moulting cases are given in Table 8, and are marked here with an asterisk.

Species. [Number of normal moults are given in square brackets.]	Morphological stage (in Roman numerals) and the number of antennal segments.								Source.
	I	II	III	IV	V	VI	VII	VIII	
1. *Patanga succincta* [7] ..	?	?	16	21	22	23	?	26 (Ad.)	Lefroy (1906), for hoppers; Roonwal (present account) for adult (1 ♂ only).
2. *Hieroglyphus banian*									
♂♂ [6]	13	16	19–20	21–22	24–25	25 26	29(Ad.)	..	Coleman and Kuhni Kannan (1911) (figures for ♀♀ are probable); and Roonwal, (present account) for adults.
♀♀ [7]	13	16	19–20	21–22	24–25	25–26	27–28	29 (Ad.)	
3. *Hieroglyphus nigrorepletus* [6]	13	14	18–20 Rarely 16–7.	Usually 21–23 (mostly 21). Rarely as low as 16.	Usually 23–25 (mostly 23). Rarely as low as 20.	Usually 26–27. Rarely as low as 14–19, and as high as 29.	Usually 27–28. Rarely as low as 20–22, and as high as 29. (Ad.)	..	Roonwal (present account).
4. *Poecilocerus pictus* [6] ..	8	8(?) –9	10–11	12–14	15	15–16	18(Ad.)	..	Pruthi and Nigam (1939) for hoppers; Roonwal (present account) for adults (2♂, 2♀).
5. *Melanoplus differentialis* [6]	12	16	18	20	23	25	26(Ad.)	..	Shotwell (1941).
6. **Melanoplus mexicanus* Sauss.									
(=*M. atlantis* Ril.) [5]	12	15	18	20	22	?(Ad.)	..	..	Shotwell (1930; 1941).
Ditto [5]	12	15	17–18	21	23–24	?(Ad.)	..	..	Uvarov (1928, p. 295).
7. *Melanoplus spretus* (supposed gregarious phase of *M. mexicanus*) [5] ..	12–13	17	20–22	24–25	26	?(Ad.)	..	..	Partly from Uvarov (1928, p. 45).
8. **Melanoplus bivittatus* [5].	13	17	19	20	22	24(Ad.)	..	..	Shotwell(1941).

9.	*Melanoplus femur-rubrum* [5]	12	16	18	20	22	24–26 (Ad.)	..	..	Shotwell (1941) for hoppers and adults; Roonwal (present account) for adults (1 ♀; 26 segments).
10.	*Melanoplus packardii* [5] ..	12	16	19	20	21	24(Ad.)	..	..	Shotwell (1941).
11.	*Melanoplus gladstoni* [5] ..	12	15	18	20	21	23(Ad.)	..	..	Shotwell (1941).
12.	*Phoetaliotes nebrascensis* [5]	11	15	18	20	23	23(Ad.)	..	..	Shotwell (1941).
13.	*Camnula pellucida* [5] ..	11	12	17	18	20	23(Ad.)	..	..	Shotwell (1941).
14.	*Dissosteira carolina* [5] ..	11	14	18	20	23	24(Ad.)	..	..	Shotwell (1941).
15.	**Colemania sphenarioides* ..	8	9–10	10–12	13–15	15–17	17–19 (Ad.)	..	..	Coleman (1911).
16.	*Locusta* [*migratoria*] *migratoria* [5].	13–14	15–19	20–21	22–23	24–25	?(Ad.)	..	..	Lobedeva, 1925 (from Uvarov, 1928, p. 45).
17.	*Locusta* [*migratoria*] *migratorioides* [5].	13	19	21	22	24–25	?(Ad.)	..	..	Uvarov (1928, p. 45).
18.	*Calliptamus italicus.*									
	♂ ♂ [5]	13	16	18–20	21–22	23–24	?(Ad.)	..		Uvarov (1928, pp. 282-283).
	♀ ♀ [6]	13	17	20–22	22–23	23–24	?	?(Ad.)	..	
19.	**Schistocerca gregaria*, 6-eye-striped. [5]	13	19	20–21	23	25	26–27 (Ad.)	..	..	Rao (1938); Mukerji and Batra (1938); Roonwal (present account).
20.	*Schistocerca paranensis* [5]	13	17	20–22	24–25	26	?(Ad.)	..	..	Uvarov (1928, p. 265).
21.	*Schistocerca americana* (supposed solitary phase of *S. paranensis*) [5]. ..	13	17	20–22	25	26	?(Ad.)	..	..	Uvarov (1928, p. 45).
22.	*Schistocerca* sp. (swarming in British Guiana, South America) [6]. ..	14	17	20	22	24	26	?(Ad.)	..	Cleare (in Bodkin and Cleare, 1919).
23.	*Dociostaurus maroccanus* [5]	13	15–17	17–20	21–22	23–24	?(Ad.)	..	..	Sviridenko (1925, from Uvarov, 1928).
	Ditto .. [5]	13	17	20	22	24	25	..	..	Paoli (1937, from Imms, 1940)
	Ditto .. [5]	13	16	20 (rarely 18).	22 (rarely 21).	24	25	..	..	Jannone (1939).

TABLE 8.

Number of antennal segments added at each moult in species of Acrididae undergoing extra-moulting and under-moulting.
(For normal moulting, see Table 7.)

Abbreviations.—Ad., adult stage; n., normal number of moults; e.m., extra-moult; u.m., under-moult; A, B, normal- and extra-stage respectively of a morphological instar or stage.*

Serial No. from Table 7.	Species. [Number of moults is given in square brackets.]	Morphological (not chronological) stage* (in Roman numerals) and the number of antennal segments.								Source; and remarks.
		I	II	III		IV		V	VI	
				A	B	A	B			
6	*Melanoplus mexicanus Sauss.* (= *M. atlantis* Ril.) [n., 5]. 1 e.m. [6].	12	15	18	19	22		23	? (Ad.)	Shotwell (1930, 1941).
8	*Melanoplus bivittatus* [n., 5]. 1 e.m. [6]	13	17	19	22	23		24	26(Ad.)	Shotwell (1930, 1941).
15	*Colemania sphenarioides* [n., 5]. 1 e.m. [6]	8	9–10	10–12	13–15	15	17	17–18	17–19 (Ad.)	Coleman (1911). Probable figures.
19	*Schistocerca gregaria* [n., 5]. 1 u.m. [4]	13	19	20–21		23		25 (Ad.)	..	Rao (1938); Mukerji and Batra (1938); Roonwal (present account).
	1 e.m. [6]	13	19	20–21	22–23	25		26–27	28–29 (Ad.)	
	2 e.m. [7]	13	19	20–21	22–23	25	27	28	30 (Ad.)	

* The 'morphological stage' is to be distinguished from the 'chronological stage' (*vide* discussion in Roonwal, 1946, pp. 79–81).

TABLE 9.

Number of antennal segments added at each moult in some Acrididae. (*From* data in Tables 1, 7 and 6.)

Species. [Number of moults indicated in square brackets.]	Number of antennal segments added at each moult (between consecutive instars I–VIII).						
	1st moult (I & II)	2nd moult (II & III)	3rd moult (III & IV)	4th moult (IV & V)	5th moult (V & VI)	6th moult (VI & VII)	7th moult (VII & VIII)
1. *Patanga succincta* [7]	..	..	5	1	1	..	..
2. *Hieroglyphus banian* (*a*) [♂ 6]	3	3–4	?	?	?	3–4	..
(*b*) [♀ 7]	3	3–4	?	?	?	?	1–2
3. *Hieroglyphus nigrorepletus* [6]	1	2–6	?	?	?	?	..
4. *Poecilocerus pictus* [6]	1	?	?	1–3	0–1	2–3	..
5. *Melanoplus differentialis* [6]	4	2	2	3	2	1	..
6. *Melanoplus mexicanus* Sauss. (= *M. atlantis* Ril.) (*a*) [5]	3	2–3	2–4(?)	2–3(?)	?	..	..
(*b*) [6]	3	3	1	3	1	?	..
7. *Melanoplus spretus* (supposed gregarious phase of *M. mexicanus*) [5]	4–5	3–5	?	1–2	?	..	..
8. *Melanoplus bivittatus* (*a*) [5]	4	2	1	2	2	..	..
(*b*) [6]	4	2	3	1	1	2	..
9. *Melanoplus femur-rubrum* [5]	4	2	2	2	2–4	..	..
10. *Melanoplus packardii* [5]	4	3	1	1	3	..	..
11. *Melanoplus gladstoni* [5]	3	3	2	1	2	..	..
12. *Phoetaliotes nebrascensis* [5]	4	3	2	3	0	..	..
13. *Camnula pellucida* [5]	1	5	1	2	3	..	..
14. *Dissosteira carolina* [6]	3	4	2	3	1	..	..
15. *Colemania sphenarioides* (*a*) [5]	1–2	?	?	?	?	..	..
(*b*) [6]	1–2	?	?	?	?	..	..
16. *Locusta* [*migratoria*] *migratoria* [5]	?	?	?	?	?	..	..
17. *Locusta migratoria migratorioides* [5]	6	2	1	2–3	?	..	..
18. *Calliptamus italicus* (*a*) [♂ 5]	3	2–4	?	?	?	..	..
(*b*) [♀ 6]	4	3–5	?	?	?	?	..
19. *Schistocerca gregaria* (*a*) 5-eye-striped [4]	6	1–2	2–3	2	..	..	..
(*b*) 6- ,, [5]	6	1–2	2	2	2	..	..
(*c*) 7- ,, [5]	?	?	?	?	?	..	..
(*d*) 7- ,, [6]	6	1–2	?	2–3	1–2	?	..
(*e*) 8- ,, [7]	6	1–2	?	2–3	2	1	2
20. *Schistocerca paranensis* [5]	4	3–5	?	1–2	?	..	..
21. *Schistocerca americana* (supposed solitary phase of *S. paranensis*) [5]	4	3–5	3–5	1	?	..	..
22. *Schistocerca* sp. (swarming in British Guiana, South America) [6]	3	3	2	2	2	..	..
23. *Dociostaurus maroccanus* [5] (From Jannone, 1939).	3	4 (rarely 2)	*ca.* 2	2	2	..	..

TABLE 10.

Frequency of the number of antennal segments added at each moult in the Acrididae. (*From* Tables 1, 7, 8 and 9.)

No. of antennal segments added →	Range.	Frequency.							Total number of species (and kinds regarding moulting) for which data are available.
		0	1	2	3	4	5	6	
1st moult .	1–6	0	5	4	10	10	1	4	29
2nd moult ..	1–5	0	5	14	14	10	5	0	26
3rd moult ..	1–5	0	6	9	5	2	2	0	18
4th moult ..	1–3	0	8	14	9	0	0	0	23
5th moult	0–3	1	7	9	2	0	0	0	17
6th moult .	1–4	0	2	2	3	2	0	0	4
7th moult ..	1–2	0	1	2	0	0	0	0	2

The increase at each moult may vary from 0–6 segments. From a study of the available data for the Acrididae (Table 10) it is seen that the number of segments added at each moult of the successive chronological moults is as follows:—

First moult: 1–6, mostly 3–4.
Second moult: 1–5, mostly 2–3.
Third moult: 1–5, mostly 2.
Fourth moult: 1–3, mostly 2.
Fifth moult: 0–3, mostly 1–2.
Sixth moult: 1–4, mostly 1 (4 cases only).
Seventh moult: 1–2 (2 cases only).

It will be seen that there is a tendency for the number of segments added at each moult to decrease with the successive chronological moults.

(viii) The increase in the number of segments at each moult does not appear to be correlated either with the initial or the final number of segments in that species, nor with the number of moults undergone during post-embryonic growth.

Thus, with the same initial number of segments in the first instar and the same number of moults in species of *Hieroglyphus* and *Melanoplus* (Table 7), the final number of segments may still vary.

(ix) Bilateral asymmetry may occur in some individuals of the older instars in a species, the remaining individuals of that instar being symmetrical. The degree of asymmetry roughly tends to increase with age, being greater in the older instars; it may also be rather more common in females than in males, especially in the older instars.

Thus, in *Hieroglyphus nigrorepletus* (Tables 1 and 3), from the third instar onward, roughly one-half the number of individuals are asymmetrical; the difference in the right and left antenna is 1–2 segments in the third stage, and is as high as 1–14 in the sixth. (For a fuller discussion of this species, *vide supra*.)

(x) In species where eye-stripe variation occurs, the number of antennal segments generally shows a positive correlation with the number of eye-stripes.

Thus, in *Schistocerca gregaria* where the number of eye-stripes varies from 5–8 (Roonwal, 1936, 1947), the 5-eye-striped (4 moult) individuals have 25 segments, the 6-eye-striped (5 moult) ones 26–27 segments, the 7-eye-striped (5–6 moult) ones 28–29 segments, and the 8-eye-striped (6–7 moult) ones 30 segments (Table 5–8). It may be added that the eye-stripe variation in this species is only partially connected with the number of moults (Roonwal, 1947).

(xi) The number of segments is also correlated with the phase-category where the phase-type of variation (see Uvarov, 1928) occurs. Phase *gregaria* individuals generally have fewer segments than phase *solitaria* ones.

Thus, in *Schistocerca gregaria* the 6-eye-striped individuals have 26 segments in phase *gregaria* and 26–27 segments in phase *solitaria* (Rao and Gupta, 1939), though both categories normally undergo only 5 moults. Among the phase *solitaria* 6-eye-striped individuals, there is noticeable, as shown above, a correlation between the E/F ratios and the number of antennal segments. Individuals with higher E/F ratios tend to have 26 segments, and those with lower ratios 27 segments. This feature is interesting in as much as phase *gregaria* individuals have the highest E/F ratios and, correspondingly, only 26 antennal segments. In other words, even in the phase *solitaria* individuals the number of segments tends to decrease as we move from the extreme *solitaria* towards the *gregaria* end of the series. In *Dociostaurus maroccarrus*, however, according to Jannone (1939, p. 416), there are 26 adult segments in all the phase-categories.

Finally, it should be emphasised that there is need for more data both regarding the number of segments in the adults and the manner of post-embryonic growth. A word regarding the technique of counting is necessary. Counting can be done in either dry or spirit specimens, and is best done in strong incident light (from an electric lamp or directly from the sun) and under a magnification of about 15 to 20 times. Transparent permanent mounts on slides are not particularly helpful. Occasionally, a segment appears to be divided into two by means of a faint transverse suture; such cases should be carefully examined to decide whether the division is real or otherwise.

V—Summary.

During post-embryonic growth in the *phadkā* grasshopper, *Hieroglyphus nigrorepletus* Bolivar, the number of antennal segments increase from 13 in the first stage to a maximum of 29 in the seventh stage or adult. The number of segments in each stage are as follows:—I, 13; II, 14; III, usually 18–20, rarely 16–17; IV, usually 21–23 (mostly 21), rarely as low as 16; V, usually 23–25 (mostly 23), rarely as low as 20; VI, usually 26–27, rarely as low as 14–19, and as high as 29; VII (adult), usually 27–28, rarely as low as 20–22, and as high as 29.

2. The characteristics of post-embryonic growth, intra-instar and intra-individual (bilateral asymmetry) in *Hieroglyphus nigrorepletus* are elucidated.

3. The post-embryonic growth in the number of antennal segments in the Desert Locust, *Schistocerca gregaria* (Forskål) is critically discussed, and some new data added. A correlation between the number of segments and the E/F ratios is shown to exist in 6-eye striped phase *solitaria* individuals, those with higher ratios having 26 segments and those with lower ratios 26–27 segments.

4. Available data on the family Acrididae on the number of antennal segments and their variation and post-embryonic growth are summarised and discussed. Based on this data, a set of general characteristics is formulated.

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STUDIES ON FOLIAR SCLEREIDS IN DICOTYLEDONS.

IV. STRUCTURE AND DEVELOPMENT OF SCLEREIDS IN THE LEAF OF *TERNSTROEMIA JAPONICA* L.

By T. ANANDA RAO, *M.R. Science Institute, Gujarat College, Ahmedabad.*

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Recent studies of Foster (1947), and Rao (1951*a*) have emphasised the importance of studying the ontogeny of sclereids in order to know whether terminal sclereids originate from procambial cells in the developing veinlets or from adjacent cells of the ground meristem. The present paper describes some observations on the ontogeny of the foliar sclereids of *Ternstroemia japonica* L.

Leaf material of *Ternstroemia japonica* was collected from different places near Coonoor. Vegetative buds as well as young and old laminae were fixed in formalin-acetic-alcohol. In addition dry specimens were secured from a number of herbaria. The fixed material was dehydrated and embedded in paraffin according to the customary methods. Sections were stained by Foster's method (1934). The leaves of herbarium specimens were cleared and macerated as outlined by Subramanyam and Rao (1949).

Distribution of Sclereids in the Mature Lamina.—In agreement with the observations of Solereder (1908), the present study has revealed the existence of 'branched sclerenchymatous cells' in the mesophyll of *Ternstroemia japonica*. These are remarkable on account of the variation in their form and structure. Besides the polymorphic form of the adaxial sclereids, cleared portions of the laminae showed an abundance of apparently terminal, sub-terminal and diffuse sclereids. A noteworthy feature is the regular pattern of their distribution. Three categories were found: (i) Adaxial sclereids showing an intimate relation with the vascular bundles; (ii) abaxial sclereids in the lacunate spongy tissue; and (iii) sclereids in the parenchymatous part of the mid-rib.

The adaxial sclereids exhibit various trends resulting in symmetrical or sometimes asymmetrical forms. They vary greatly both in size and form (Figs. 15–22), from unbranched forms to stellately branched ones. The latter show long arms, sometimes forked and occupying considerable portion of the palisade and spongy regions. Whatever their form, some of the sclereids exhibit a close association with the foliar veins (Figs. 4–9).

Unlike the adaxial sclereids, the sclereids in the abaxial region of the lamina are situated in the midst of well-developed air-spaces with their arms lying free in the lacuna. Sclereids of this type have been reported in a large number of angiosperms and have been described quite recently in the leaf of *Trochodendron aralioides* (Foster, 1945*a*). A transection of the mature leaf shows the presence of idioblastic abaxial sclereids at various levels in the spongy parenchyma. They do not exhibit as much variation as the adaxial sclereids. All of these have a more or less stellate form with radiating arms of limited growth (Figs. 23–28). These diffuse sclereids do not show any connection with the vascular bundles.

In the parenchyma of the mid-rib region, the sclereids are more densely aggregated. They are abundant on the abaxial side of the mid-rib region. Their arms are short or drawn out and they exhibit an irregular form. Sometimes their arms come in close proximity to the foliar bundle.

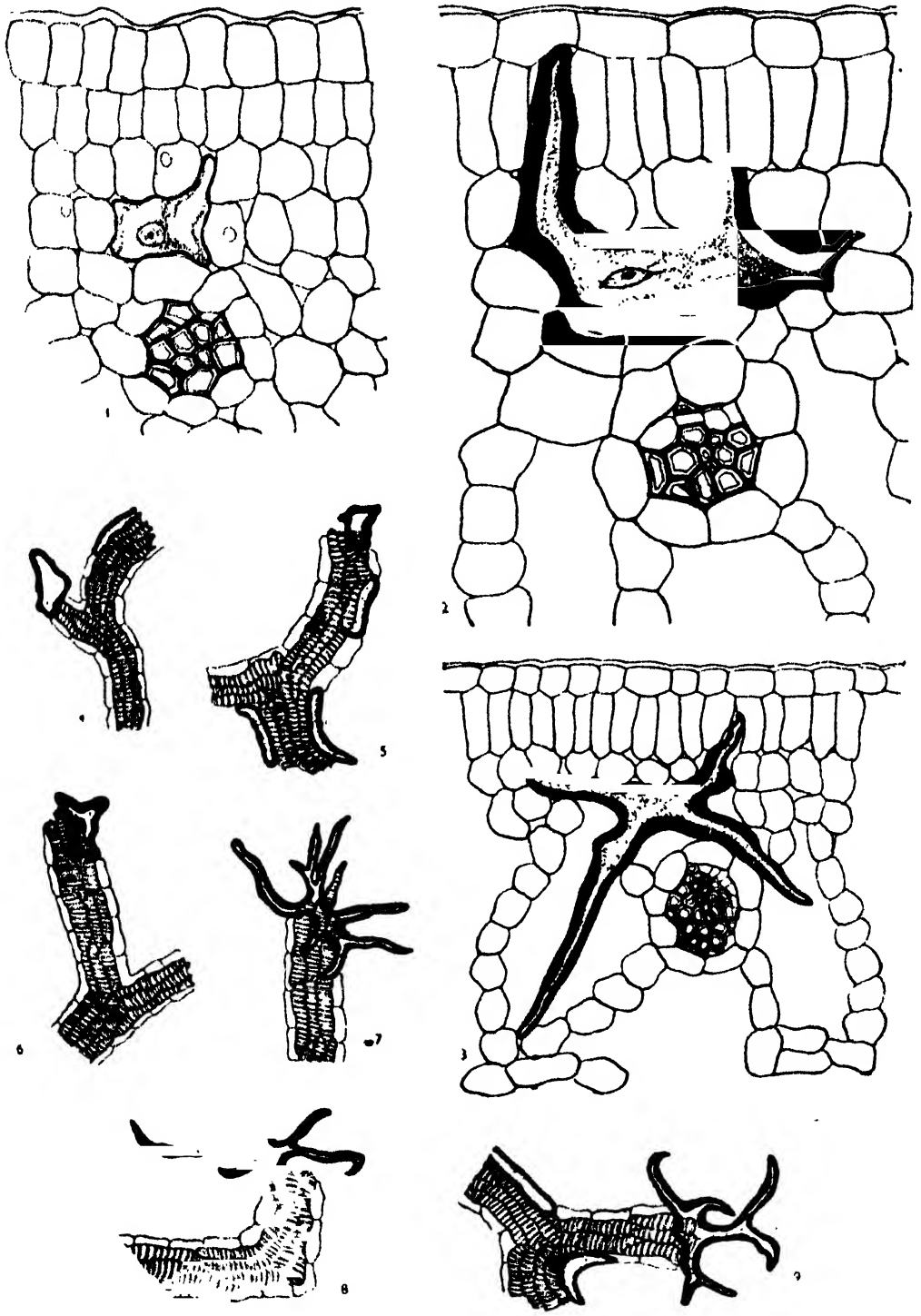

FIG. 1. Transection through submarginal portion of young lamina with very young sclereid initial showing adaxial and abaxial processes. ×450.

,, 2. More advanced stage. Note the conspicuous nucleus and the proximity of the sclereid to the vascular bundle. ×450.

,, 3. Transection of mature lamina showing pseudoterminal sclereid. Note the sharp abaxial processes lying in proximity to the vein-bundle. ×225.

FIGS. 4–9. Sclereids from cleared portions of mature lamina showing their proximity to veinlets. ×125.

Structurally, the adaxial sclereids show a vigorous growth and have a broad lumen in the centre which narrows towards the arms and finally becomes much reduced. The cell wall is homogeneous and free from spicules. The abaxial sclereids are similar to the adaxial, but they are less vigorous in growth and their arms are shorter. The sclereids of the mid-rib region present a strong resemblance to adaxial ones, but they are 'cell forms' of limited variation. The processes lie in small air-spaces and exhibit the same structural features.

Sclereids of the Mid-rib Region.—As in a previous study (Rao, 1951*a*) developmental stages of the sclereids were traced from sections of young leaves selected from unfolding leaf-buds. The unexpanded young lamina is composed of closely packed cells and neither sclereid initials nor air-spaces are distinguishable. Transections of the expanding laminae exhibit a slight tissue differentiation in the abaxial part and in the ground parenchyma of the mid-rib region. The sclereid initials appear first on the adaxial and abaxial sides of the mid-rib. They are either isolated or appear in groups of 3 to 5. They are polyhedral in shape with a large central nucleus and radiating strands of cytoplasm (Figs. 10–11). Small air-spaces now appear, especially in the abaxial region of the mid-rib. Thus the sclereids initials and air-spaces originate at about the same time. In the next phase of development the walls of the sclereid initials become slightly thicker and throw out plug-like processes in all directions. The mode of growth is intercellular. As noted by Sterling (1947), Foster (1944) and Rao (1951*a*), the sclereid arms show a strong tendency to make their way towards an air-space. The entry of the arms into the air-space seems, however, to stop their further growth. The cell wall now thickens considerably and the lumen of cell is almost entirely obliterated in the arms.

The Abaxial Sclereids.—With the development of sclereids in the mid-rib vertical air-spaces appear in the spongy tissue of the sub-marginal part of the leaf. It is during this phase of expansion of the spongy region that the abaxial sclereid initials become recognisable (Fig. 12). As in *Trochodendron aralioides* (Foster, 1945*b*) the sclereid initials originate at various levels of the septa which separate the air-spaces. At this stage the septal layer is composed of a vertical row of young spongy cells. As reported by Foster (1945*b*), Bloch (1946), Sterling (1947) and Rao (1951*a*) the idioblastic sclereid initials show a large nucleus with radiating strands of cytoplasm. The sclereid initial cells are mostly sub-spherical with thin cellulose wall. The enlargement of the sclereid initial coincides with the vertical and transverse expansion of the air-space. The first stage of the growth of the sclereid initial cell is the appearance of blunt processes, especially at the corners (Figs. 12–13). These processes make their way into the air-space. With the development of the processes the cytoplasm is thick around the nucleus but shows parietal disposition in the developing arms. The sclereid processes have a limited growth and occupy a small portion of the air-space. At maturity they possess a broad central lumen which narrows towards the arms (Fig. 14). As noted by Rao (1951*a*) the nucleus can be observed up to a late stage in the lignification of the sclereid (Fig. 14).

The Adaxial Sclereids.—The adaxial sclereid initials are initiated in the third layer beneath the upper epidermis (Fig. 1), at a somewhat later stage than the abaxial sclereids. At the time of their initiation the lamina shows a good degree of tissue maturation, with a well-organised cuticle and palisade region. The vascular bundles are also fairly well organised. At this phase of leaf expansion, the mesophyll cells beneath the palisade layer are closely packed without any air-spaces. On the contrary, the abaxial region of the lamina possesses clear vertical clefts and well-developed sclereid initials.

In the light of the occurrence of 'terminal sclereids' in *Mouriria huberi* (Foster, 1947), *Memecylon heyneanum* (Rao, 1951*b*), *M. Lushingtonii* and *Niehburia apetala* (Rao, in press) microtome sections of *Ternstroemia* were examined to see whether

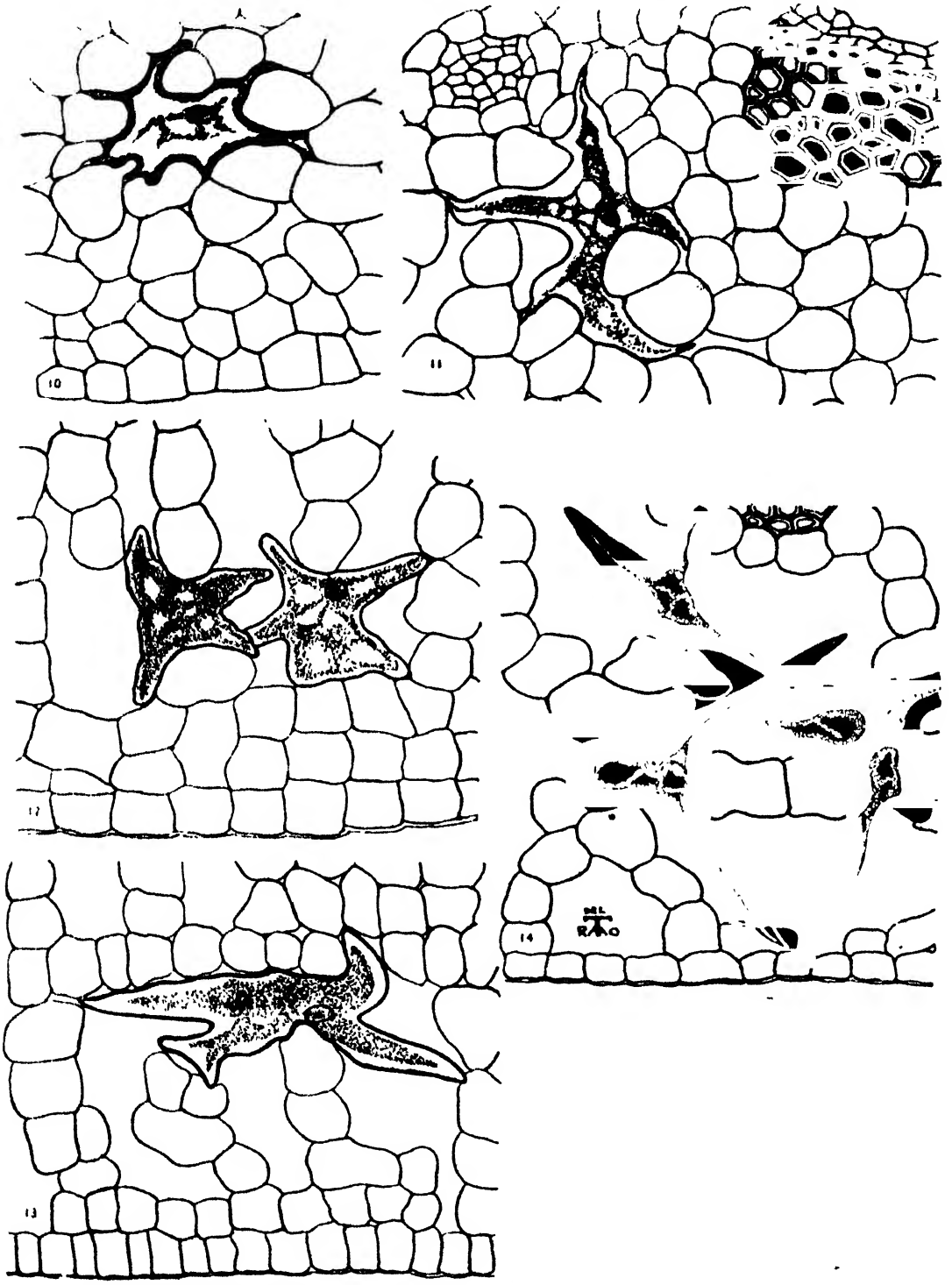

FIG. 10. Sclereid initial in the midrib portion. ×450.
,, 11. Sclereid initial showing prominent processes. Note approximation of adaxial process to vascular bundle. ×450.
FIGS. 12-13. Transections of young laminae showing early stages in ontogeny of abaxial sclereids. Note the prominent processes protruding into the developing and expanding air-clefts. ×450.
FIG. 14. More advanced stage of abaxial sclereid showing a prominent nucleus and cell wall with pit-canals. ×450.

the sclereid initials are differentiated at the tips of the procambial strands. As in *Diospyros* it was confirmed that the adaxial sclereid initials originate just above the vascular bundle and not from the same procambial strand.

The adaxial sclereid initial, which is more or less rectangular in transection, shows plug-like processes at the corners (Fig. 1). These processes elongate in all possible directions; sometimes entering the air-spaces of the spongy tissue. In all cases the growth is intercellular. By virtue of their close juxtaposition with the vascular bundle, they exhibit a prevailingly terminal or sub-terminal position (Figs. 2–3). The sclereid initial shows a prominent nucleus with radiating strands of cytoplasm. The mature adaxial sclereids possess a homogeneous cell-wall and pit canals. The nucleus can be recognised for a long time. In later stages, it becomes pear-shaped, a feature also seen in the growing sclereids of *Olea* (Rao and Kulkarni, 1952), *Memecylon* (Rao, 1951*b*), *Linociera intermedia* and *Niehburia apetala* (Rao, in press)..

Conclusion.

The present study shows that sclereid initials in different regions of the leaf do not differentiate simultaneously. The first to appear are the sclereids of the mid-rib region; these are followed by those of the spongy region; and finally, the adaxial part. As noted in *Trochodendron* (Foster, 1945*b*), the origin of the sclereid initials is not limited to the early phases of tissue maturation.

Regarding the relation between air-spaces and sclereid initials, the sclereid initials of the spongy region form processes which project freely into the adjoining air-space. The arms of the adaxial sclereid initials, on the other hand, grow vigorously in an intercellular fashion, although, sometimes they grow further and penetrate into the air-spaces of the spongy tissue (Fig. 3).

The arms of the sclereids in the mid-rib region may also work their way towards the adjacent air-spaces. The air-space seems to arrest the further growth of the arms, since in the absence of an air-space the arms grow more vigorously.

As in *Diospyros discolar* (Rao, 1951*a*) and *Linociera intermedia* (Rao, in press) the apparent terminal position of adaxial sclereids is due to a close juxtaposition of the sclereids to the vein-ends. These pseudo-terminal sclereids exhibit much variation and pronounced growth. The significance of this is so far unknown.

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Summary.

The sclereids in the cleared leaf of *Ternstroemia japonica* show apparent terminal and diffuse distribution with reference to veinlets. The sclereid ontogeny has revealed that sclereid initials appear in three stages of tissue expansion. They are in fact transformed spongy cells and the apparent terminal position of some of the adaxial sclereids is due to juxtaposed and vigorous development near the veinlet. The study emphasises the need for ontogenetic study to prove the real relationship between procambial layer and the sclereid initials.

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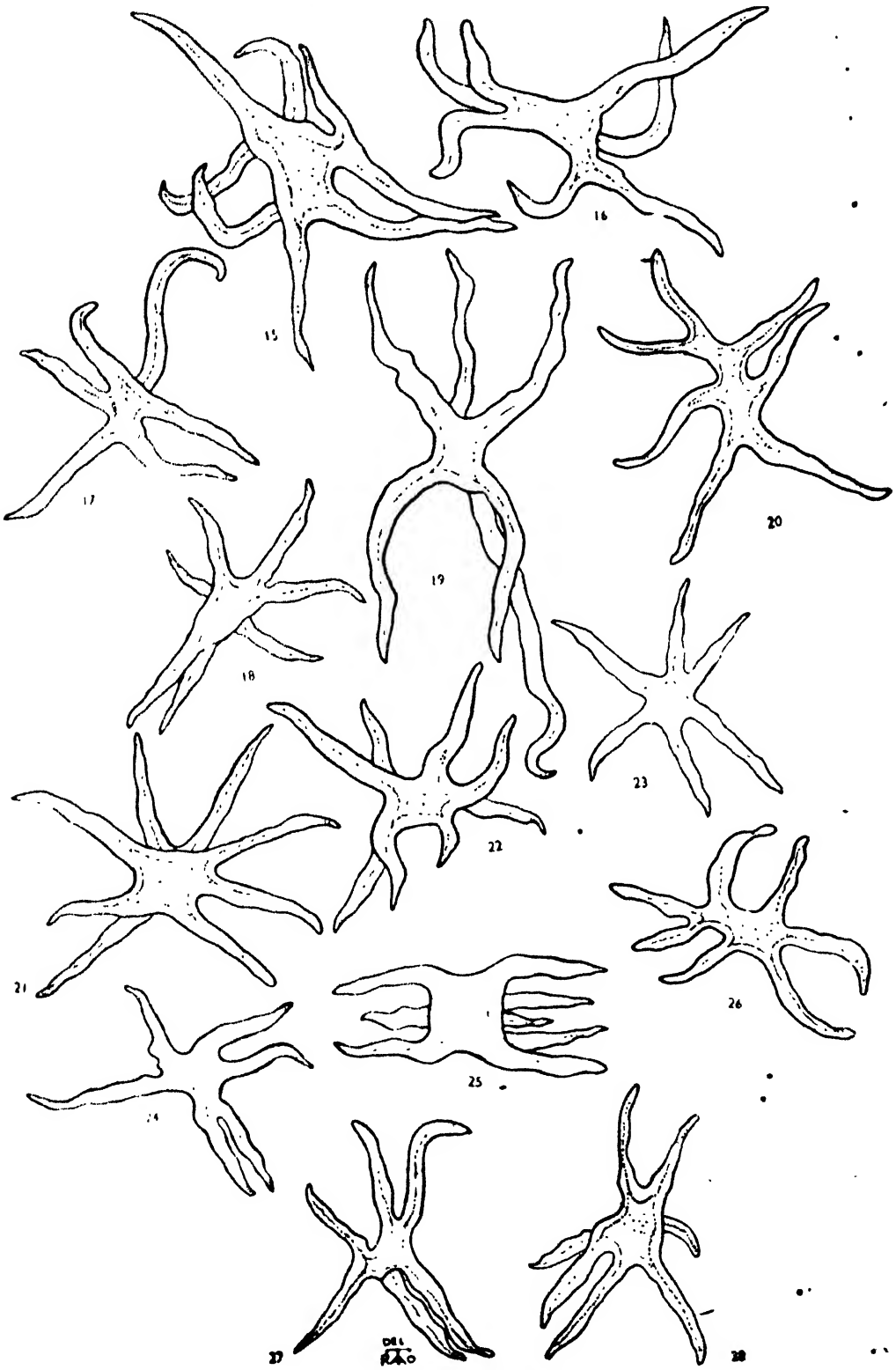

FIGS. 15–22. Polymorphic adaxial sclereids. ×225.
,, 23–28. Polymorphic abaxial sclereids. ×225.

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ON THE NEPHRIDIA OF NEREIDAE IN RELATION TO HABITAT.

By G. KRISHNAN, *M.Sc., Ph.D., Department of Zoology, University of Madras.*

(Communicated by Prof. H. K. Mookerjee, D.Sc.(Lond.), D.I.C., F.N.I.)

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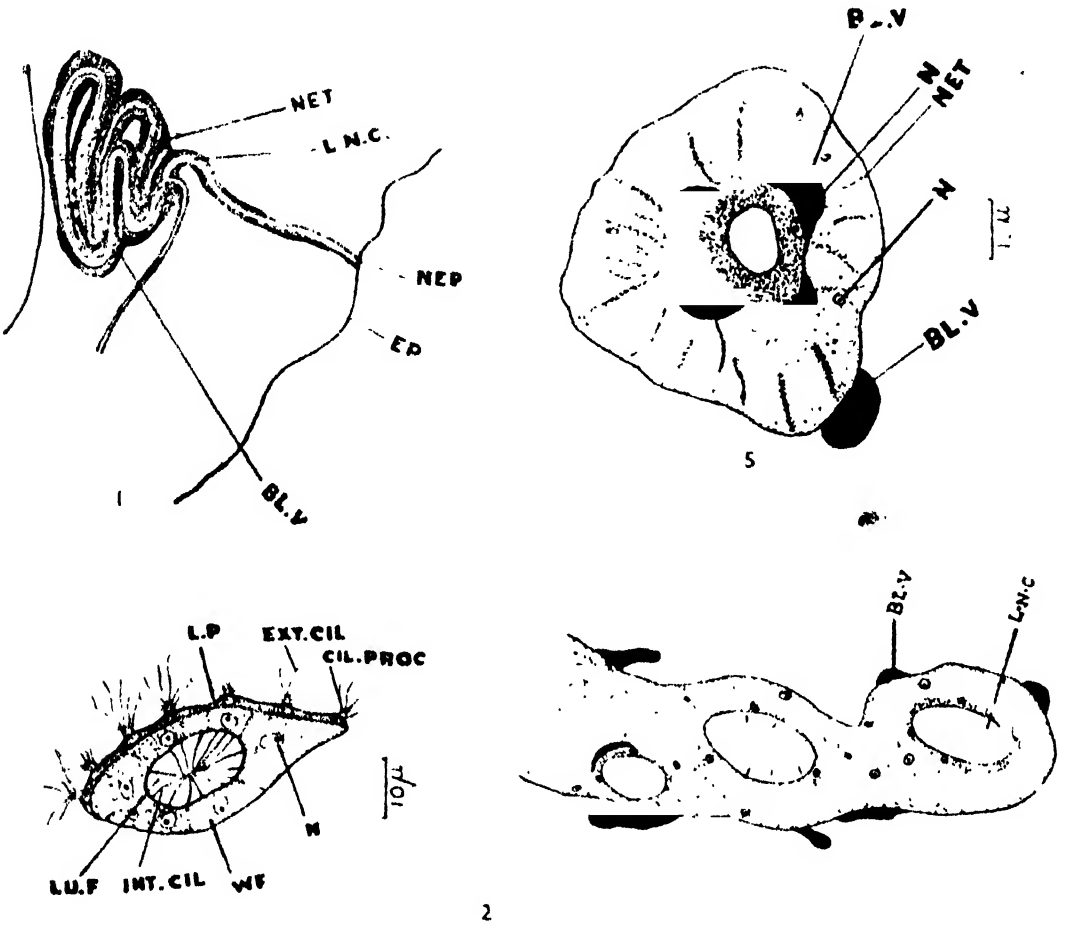
1. INTRODUCTION.

Beadle (1937) has suggested that in *Nereis diversicolor*, which is able to withs and lowering of the salinity of the external medium, the nephridia may be responsible for the necessary osmotic adjustments. A similar relationship between the nephridia and the ability to survive low salinity conditions has been shown to exist in *sabella pavonina* by Ewer and Ewer (1943). Since closely allied species differ widely in their osmotic behaviour and therefore in their ability to thrive in waters of low and varying salinity it was thought that an examination of the nephridia in such species would be of interest, as it might reveal whether the nephridia which perform osmoregulatory functions show correlated anatomical variations. Hitherto work on nephridia of polychaetes was carried out without reference to the external medium. In the following study an attempt is made to compare the nephridia of allied species of Nereidae from the sea and brackish water to find if any relation exists between the nephridia and the salinity of the external medium.

2. MATERIAL AND METHODS.

The material for this study consists of the following Nereids: *Lycastis indica* Southern, *Nereis chilkaensis* Southern and *Pereinereis nuntia* Savigny. *Lycastis indica* was collected from the brackish waters in the vicinity of Madras where it is abundantly distributed. In this habitat there is a wide seasonal fluctuation in salinity. (Panikkar and Aiyar, 1937). *Lycastis indica* occurs very close to the sea as well as in the inner reaches of the brackish water area where the water is almost fresh. In the laboratory it has been kept for months in fresh water in a healthy condition. Though it shows a marked tolerance to salinity changes it has not so far been encountered in the sea. *Nereis chilkaensis* was taken from the Madras harbour where it occurs in large numbers in the midst of sedentary organisms which are attached to the buoys and boulders. The harbour is an artificial enclosure of about quarter of a square mile in area enclosed by concrete breakwaters. The

investing its lumen (Fig. 5, Ph.m 1 and 2). In transverse sections the blood capillaries are seen forming a ring round the canal. After coursing through the inner



Lycastis indica:

FIG. 1. An optical section of the nephridium (diagrammatic) showing the different regions of the canal. The nephridiostome is not shown in the figure.
FIG. 2. A transverse section through the nephridiostome.
FIG. 5. A transverse section through the wider non-ciliated part of the nephridial canal showing the position of blood capillaries.
FIG. 6. A section through a part of the nephridium of a worm acclimatised to sea-water.

and outer loops of the nephridium the canal emerges out of the body of the nephridium and runs towards the lateral border of the ventral longitudinal muscle where it opens by the nephridiopore.

The connective tissue which envelopes the nephridial canal is much vacuolated (Fig. 5). The nuclei of these cells are small and loosely arranged fibrils of various degrees of thickness are seen in the connective tissue and also in the cytoplasm of the cells of the canal. They pass circularly round the non-ciliated part of the canal. The appearance and distribution of these fibrils are similar to those in *Nereis diversicolor*. It is not known what function they serve in Polychaetes. They recall the so-called resistance fibrillae known to be of wide occurrence in the

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nephridia of Oligochaeta, where it has been suggested that they function in preventing a too extreme compression of the walls of the nephridial canal (Stephenson, 1930).

The blood supply to the nephridium is highly developed. It comes from a lateral vessel which arises as a branch from the ventral longitudinal vessel. This vessel runs to the gill, and close to the body of the nephridium gives off a number of branches one behind the other to the nephridium. Each such branch divides forming a cluster of twigs which spread over the nephridium. The capillaries penetrate the connective tissue enclosing the nephridial canal and come to lie in close association with the distal part of the nephridial canal (Fig. 5, Ph.m. 1 and 2). In this position the blood capillaries are separated from the lumen of the nephridial canal by the narrow cells lining the canal. Another feature of the vascular supply to the nephridium is the presence of blind-ending capillaries with minute dilatations on them (Ph.m. 1). These do not appear to have been described so far, in the Nereidae. The ampullae, as these dilatations have been called, are of wide occurrence in many Oligochaetes (Stephenson, 1930) and have also been observed in a few Polychaetes. Benham (1891) noted them in the blood vessels supplying the nephridium in species of *Arenicola*. Their functional significance is obscure. Gegenbaur (as quoted by Benham, 1891) thought that they are connected with the reproductive function. Claparédé (1869) figured them as being filled with corpuscles which might suggest that they subserve the excretory function. The blind-ending capillaries have been noted in relation to the nephridia in widely separated species such as *Marphysa sanguinea* (Fuchs, 1907) and *Lanice conchilega* (Meyer, 1888). It is possible that they occur more widely than at present known. Their occurrence appears to be somewhat erratic being found in one species and absent in other closely related species. Ewer (1941) noted them on the segmental organ of *Travesia forbesii* but Brown (1938) who worked on the allied *Ophelia cluthensis* failed to see them. Ewer discusses at some length the possible function of the blind-ending capillaries and concludes that in the absence of a more complete knowledge of the mechanics and physiology of circulation, their significance, if any, must remain a matter for speculation.

Tables I and II show the relation between the size of the nephridium and the size of the animal. An attempt is here made to compare the size of the nephridium with the body weight as well as with the cubic capacity of a single average segment.

TABLE I.

	Worm.					Nephridium		
No.	Length of the worm. mm.	No. of segments.	Length of a segment. mm.	Breadth of a segment. mm.	Height of a segment. mm.	Length of the body. μ	Breadth of the body. μ	Height of the body. μ
1	56	95	·568	1·50	·929	190	146	269
2	89	130	·685	1·75	·888	240	170	296
3	82	125	·655	1·60	·942	210	152	310
4	102	126	·806	2·50	1·211	290	272	471
5	54	75	·720	2·20	·915	270	238	444
6	130	148	·878	2·60	·942	310	242	256

Table I gives the dimensions of a single segment and the size of the nephridium. Table II shows the relation between the body weight both dry and wet weight and the size of the nephridium.

TABLE II

	Worm.						Nephridium.		
No.	Length of the worm mm	No. of segments	Girth of a segment, mm	Wet weight gm.	Dry weight gm	% of water	Length of the body μ	Breadth of the body μ	Height of the body. μ
1	56	95	1·50	·300	·045	85·00	190	146	269
2	89	130	1·75	·550	·062	88·73	240	170	296
3	82	125	1·60	·505	·060	88·12	210	152	310
4	102	126	2·50	·755	·082	89·14	290	272	171
5	54	75	2·20	·558	·041	92·65	270	238	141
6	130	148	2·60	1·050	·105	90·00	310	242	256

It is seen that the percentage of water varies between 85 and 92. A comparison of these values with those relating to the specimens acclimatised to sea-water is interesting. Table III shows the values for the weight of animals which have been acclimatised to sea-water.

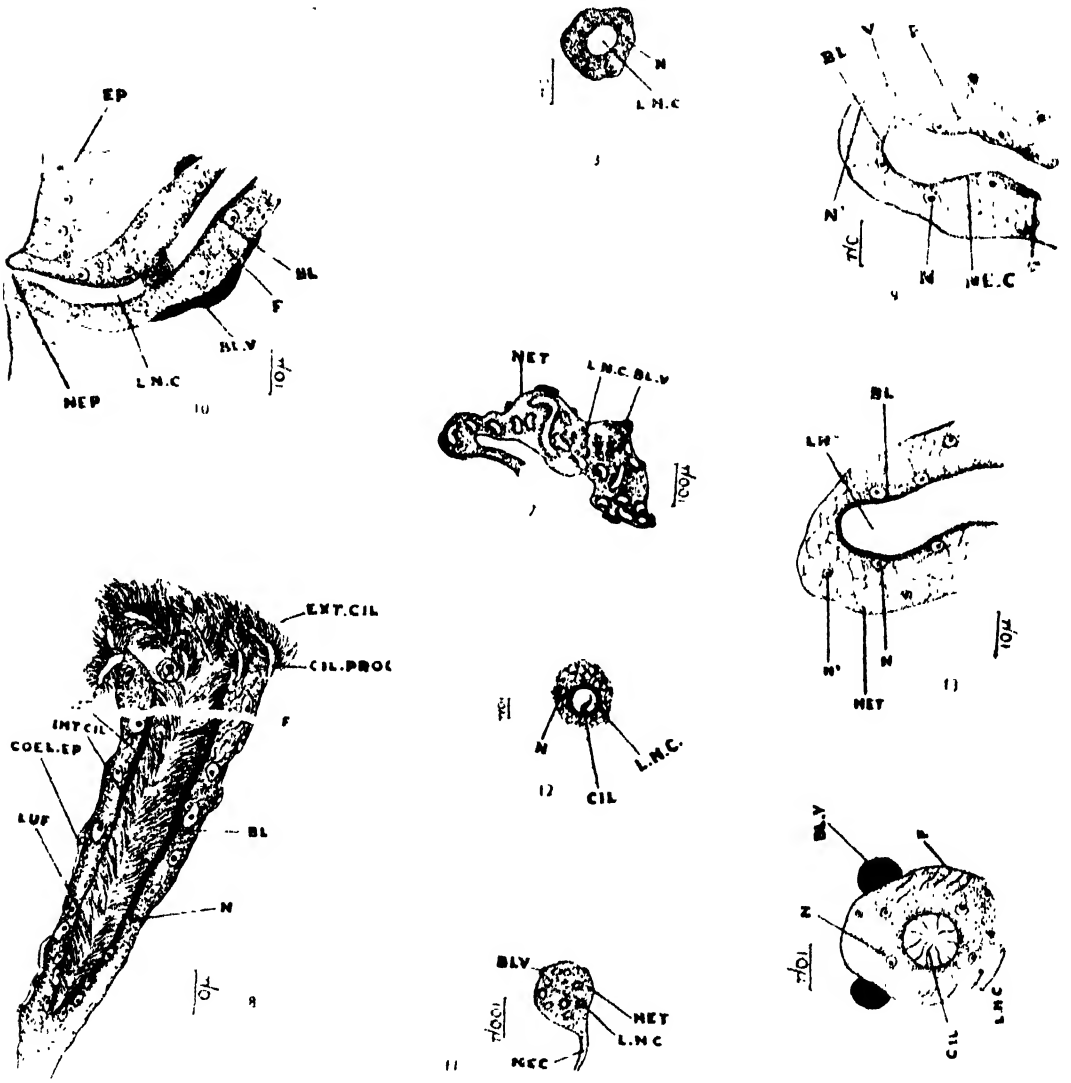
TABLE III

No.	Length of the worm, mm.	No. of segments.	Girth of a segment, mm	Wet weight gm	Dry weight gm.	% of water
1	48	78	1·50	·165	·030	81·82
2	50	80	1·45	·150	·023	84·67
3	45	75	1·40	·125	·030	76·00
4	110	135	2·50	·475	·065	86·31
5	99·5	132	2·55	·455	·060	84·62

It is seen that there is a fall in weight of the animals compared to those living in their normal habitat, i.e. fresh water. The change in weight on transference to sea-water might indicate an upset of the osmotic equilibrium due to a change in the concentration of the external medium resulting in water movements between the body fluids and the external medium as has been noted in a number of animals. Panikkar (1941) pointed out that *Leander serratus* and *Palaemonetes varians* when transferred from dilute to concentrated sea-water showed a fall in weight which is due to the escape of water to the exterior.

The importance of the nephridia in the regulation of the water balance of these worms is indicated in the changes that have been observed in the nephridia of specimens acclimatised to sea-water. Sections prepared of specimens after a fortnight's stay in sea-water show that the blood supply to the nephridium has undergone a marked diminution as seen from the appearance of the blood capillaries of the nephridium. This is in contrast to what is seen in the sections of nephridia of the controls which had been in fresh water. In the latter the capillaries form a conspicuous feature. The ampullae and the capillaries that surround the lumen of the nephridial canal show a bulged out appearance being filled with blood. On the other hand, in the test animals the capillaries become shrunk and shrivelled due possibly to the diminished flow of blood in them (Fig. 6 and Ph.m. 3). Some of the smaller vessels do not show at all possibly due to complete collapse. This is

free case in regard to the vessels surrounding the distal part of the nephridial canal is well seen in the sections of the controls. The possibility of such an appearance being an histological artefact is ruled out by the circumstance that in all the test animals sectioned, this feature is invariably seen, whereas in not a single specimen of the controls prepared by an identical technique is a similar condition met with.



Lycastis indica:

Fig. 3. A transverse section of the nephridial canal immediately following the funnel.
Fig. 4. A transverse section through the ciliated part of the nephridial canal.

Nereis chilkaensis:

Fig. 7. A section passing through the body of the nephridium.
Fig. 8. The nephridiostome as seen in a longitudinal section showing the ciliated processes.
Fig. 9. A longitudinal section through the non-ciliated part of the nephridial canal inside the body of the nephridium.
Fig. 10. A section through the last part of the nephridial canal and the nephridiopore.

Perinereis nuntia:

Fig. 11. A section passing through the body of the nephridium.
Fig. 12. A transverse section through the ciliated part of the nephridial canal.
Fig. 13. A longitudinal section through the wider non-ciliated part of the nephridial canal.

The reduced blood supply to the nephridium in animals acclimatised to sea-water might indicate that the nephridia in these are probably doing less osmotic work than in the normal forms living in fresh water.

(*c*) *Nephridia of Nereis chilkaensis*:

The nephridia are arranged in pairs in all segments excepting a few segments at either end of the worm. Each nephridium lies at the entrance to the parapodial cavity between the ventral cirrus and the lateral border of the ventral longitudinal muscles and has an elongated oval-shaped body made up of a mass of connective tissue cells. The channel for the passage of the excretory fluid is a long coiled canal which runs a tortuous course in the body of the nephridium (Fig. 7). The canal emerges free from the body of the nephridium on its ventral side and runs towards the body cavity ventrolaterally to open to the exterior by the nephridiopore which is a small opening in the ventral epidermis on the outer side of the lateral border of the ventral longitudinal muscles. Dorsally, the nephridial canal is continuous with a narrow duct which runs a winding course towards the body cavity where it opens in front of the anterior septum by a funnel-shaped nephrostome (Fig. 8) which carries a number of finger-shaped processes along the edge of the funnel. These processes are short and stumpy and more or less resemble those of *Nereis diversicolor*. But the lip of the funnel is not reflected and the finger-shaped processes are confined to the free margin of the funnel. The cells of the funnel are large and vesicular with prominent spherical or oval nuclei which contain in addition to a deeply staining nucleolus smaller nucleolar bodies. The cell boundaries are not clear and the cytoplasm is granular. A prominent feature of these cells is the dark staining inner border which forms a lining to the funnel. Fibrillar structures are clearly seen in the cytoplasm of these cells similar to those found in the body of the nephridium. The outer surface of the funnel is covered with coelomic epithelium. In some of the preparations a few cells are seen adhering to the margin of the funnel. The condition is similar to that observed in many Oligochaetes where such have been shown to be coelomic corpuscles in the process of giving up the excretory products or getting disintegrated to be finally thrown out to the exterior through the nephridium (Stephenson, 1930).

The first part of the nephridial canal leading from the funnel is of narrow lumen. The cells bordering the lumen are flattened, and without cilia. The canal on entering the body of the nephridium is ciliated for some length. The arrangement of the cilia appears to vary in different regions of this part of the canal. The cell limits are absent, and the nuclei appear at intervals. After coiling about within the body of the nephridium, the ciliated part passes into the next division which is characterised by the absence of cilia (Fig. 9). This part of the canal is considerably longer than the preceding division and has a wider lumen. The lining cells are larger in size, and vacuolated. The cells are also distinguished by a well-marked inner boundary layer which stains dark with iron haematoxylin and by the occurrence of fibrillar structures in the cytoplasm. The canal leaves the body of the nephridium ventrally and runs directly to the nephridiopore which is a small opening on the ventral epidermis. Close to the nephridiopore as seen in sections are two large nuclei one on each side at the terminal part of the nephridial canal (Fig. 10). The connective tissue which invests a greater part of the nephridial canal consists of cells which are vacuolated. The degree of vacuolation varies in different regions of the body of the nephridium.

The blood supply to the nephridium seems to be less developed than in *Lycastis*. Blood comes from a lateral branch of the ventral blood vessel, which on entering the parapodial cavity gives off a bunch of fine branches which further subdivide and spread over the nephridium. The blood capillaries lie between the coelomic epithelium and the connective tissue. The blood from the nephridium is returned to a lateral vessel which comes from the parapodium and joins the dorsal

longitudinal vessel. The blood vessels are not only fewer but they differ markedly in their position relative to the nephridial canal. The blind-ending capillaries and the ampullae so well seen in *Lycastis* are absent in this species. Table IV shows the size of the nephridium relative to that of the segment in which it lies.

TABLE IV.

	Worm.					Nephridium.		
No.	Length of the worm. mm.	No. of segments.	Length of a segment. mm.	Breadth of a segment. mm.	Height of a segment. mm.	Length of the body. μ	Breadth of the body. μ	Height of the body. μ
1	35	66	·530	1·20	·646	104	128	81
2	33	65	·509	1·00	·566	96	120	81
3	48	72	·667	1·50	·980	144	187	108
4	38	60	·633	1·10	·781	128	140	67
5	36	64	·563	1·20	·727	104	162	94
6	30	52	·577	1·20	·781	96	135	108

TABLE V.

	Worm.						Nephridium.		
No.	Length of the worm. mm.	No. of segments.	Girth of a segment. mm.	Wet weight worm. gm.	Dry weight worm. gm.	% of water.	Length of the body. μ	Breadth of the body. μ	Height of the body. μ
1	35	66	1·20	·100	0·028	72·00	104	128	81
2	33	65	1·00	·120	0·032	71·67	96	120	81
3	48	72	1·50	·300	0·045	85·00	144	140	108
4	38	60	1·10	·085	0·025	70·59	128	110	67
5	34	64	1·20	·175	0·041	76·57	104	162	94
6	30	52	1·20	·125	0·027	78·40	96	135	108

Comparing these values with the corresponding ones in *Lycastis* it will be seen that the nephridium in *Nereis chilkaensis* is smaller relatively to the size of the segment. The relation between the size of the nephridium and the size of the animal on the basis of the body weight is given in Table V. In the same table are given d.y weights of the animal. *Nereis chilkaensis* unlike *Lycastis indica* is not able to survive in fresh water. Acclimatisation experiments on this species show that the degree of tolerance to changes in the salinity of the external medium is limited. But compared with many of its marine relatives, it shows a certain endurance to changes in the salinity.

(d) Nephridia of Perinereis nuntia:

The nephridia of *Perinereis nuntia* resemble in their lay out and general features of their structure those of *Nereis chilkaensis*. As in the latter the nephridia occur segmentally at the entrance to the parapodial cavity. Fig. 11 shows a section

through the body of the nephridium. It is somewhat oval in outline and is formed of a mass of connective tissue through which the nephridial canal winds in a complicated manner. The histological features of the connective tissue present a close similarity to the condition seen in other Nereidae. In the nephridial canal the same divisions as were made out in *Nereis chilkaensis* could be seen. Fig. 12 shows a section through the ciliated part of the canal and Fig. 13 shows a section through the wider non-ciliated part of the nephridial canal. The blood supply to the nephridium is poorly developed. The delicate twigs of vessels on the nephridium so well seen in *Nereis chilkaensis* are here markedly reduced. A few small vessels that are seen on the nephridium arise as in the allied species of *Nereis* from a branch vessel which supplies the parapodium. The blind-ending capillaries and the ampulla are absent.

Table VI gives the dimensions of the body of the nephridium relative to the size of an average segment of the animal. From the values obtained it is seen that the size of the nephridium is smaller compared to that of *Nereis chilkaensis* and *Lycastis indica*.

TABLE VI.

	Worm.					Nephridium.		
No.	Length of the worm. mm	No. of segments.	Length of a segment mm	Breadth of a segment mm	Height of a segment mm	Length of the body μ	Breadth of the body μ	Height of the body. μ
1	64	85	·753	2·80	1·890	96	94	188
2	50	58	·862	2·00	1·080	80	81	162
3	58	65	·892	2·50	1·620	96	81	135
4	40	62	·645	1·00	0·912	72	67	107
5	36	64	·563	0·80	0·673	72	61	94

In Table VII are given the size of the nephridium in relation to the body weight of the animal.

TABLE VII.

	Worm.						Nephridium.		
No.	Length of the worm mm	No. of segments	Girth of a segment. mm	Wet weight worm. gm	Dry weight worm. gm.	% of water.	Length of the body. μ	Breadth of the body. μ	Height of the body. μ
1	64	85	2·80	·425	·095	77·65	96	94	188
2	50	58	2·00	·282	·062	78·01	80	81	162
3	58	65	2·50	·180	·048	73·33	96	81	135
4	40	62	1·00	·155	·025	83·87	72	67	107
5	36	64	0·50	·055	·010	81·82	72	61	94

4. COMPARISON OF THE NEPHRIDIA.

The nephridia in all the three species examined are disposed metamerically in all segments excepting a few anterior and posterior segments. In *Nereis chilkaensis*

and *Perinereis nuntia* the nephridium is situated ventro-laterally at the entrance to the parapodial cavity, while in *Lycastis indica* the nephridium is more centrally located in the body cavity on either side of the alimentary canal. The histological features of the canal and the connective tissue enveloping the canal are similar in all the three species. The nephrostome occupies the same position and shows similar structural details except that in *Lycastis indica* the margin of the funnel is reflected and processes carrying cilia arise from the reflected surface also. A notable difference between the nephridia of *Lycastis indica* and of *Nereis* apart from size, is in regard to blood supply. *Nereis chilkaensis* shows comparatively a richer blood supply than *Perinereis nuntia*. The same blood vessel supplies the nephridium in *Lycastis* and *Nereis* but *Lycastis* differs from the two allied species of Nereidae not only in the profuse blood supply but also in the manner of distribution of the blood capillaries and in the presence of dilatations on some of the capillaries. The penetration of capillaries into the connective tissue so as to come in close proximity with the nephridial canal is significant. The part played by the nephridium in all the three species is apparently the same but it appears to differ quantitatively. The nephridium in *Lycastis indica* appears to be an elaboration of the structure met with in *Nereis chilkaensis* and *Perinereis nuntia*.

Although the nephridia are similar in structure in all the three species, they show marked differences in size.

Table VIII gives the values of the index of volume of the nephridium relative to that of the segment. It will be seen that the average ratio between the index of volume of the nephridium and that of the segment shows marked differences in the three species. In Table IX are given the deviations from the average ratio and the square root of the deviations. The 'students' 't' test was applied to verify whether the differences noted above really exist in the species or whether they are only due to variations in sampling. It was found that for *Lycastis indica* and *Nereis chilkaensis* the value of 't' calculated from the observations made is 7·627 whereas the value of 't' at 1% level for 10 degrees of freedom is 3·169. Since the value obtained from the readings is higher it would appear that the differences in the ratio of the index volume of the segment and that of the nephridium between the two types studied exist in the species and are not due to errors in sampling. Similarly the readings obtained for *Lycastis indica* and *Perinereis nuntia* give the

TABLE VIII.

	Lycastis indica.			*Nereis chilkaensis.*			*Perinereis nuntia.*		
No.	Index of Vol. of segment. Cu. microns.	Index of Vol. of nephridium. Cu. microns.	Index of ratio of Vol. of S. & N. %	Index of Vol. of segment. Cu. microns.	Index of Vol. of nephridium. Cu. microns.	Index of ratio of Vol. of S. & N. %	Index of Vol. of segment. Cu. microns.	Index of Vol. of nephridium. Cu. microns.	Index of ratio of Vol. of S. & N. %
1	3·491508	·007462	0·943	·410856	·001078	0·262	4·098730	·001697	0·041
2	1·037850	·012077	1·164	·287585	·000933	0·324	1·861920	·001050	0·056
3	0·987216	·009895	1·002	·980490	·002908	0·297	3·612600	·001050	0·029
4	2·440165	·037152	1·522	·537810	·001200	0·223	0·607590	·000516	0·085
5	1·449360	·028531	1·969	·491161	·001603	0·326	0·303119	·000413	0·136
6	2·106398	·019205	0·912	·540764	·001399	0·259	..	..	..
	Average ratio:		1·252			0·281			0·069

TABLE IX.

No.	*Lycastis indica.*			*Nereis chilkaensis.*			*Perinereis nuntia.*		
	Index of ratio of Vol. of S. & N. %	Deviation average.	Square root of deviation.	Index of ratio of Vol. of S. & N. %	Deviation average.	Square root of deviation.	Index of ratio of Vol. of S. & N. %	Deviation average.	Square root of deviation.
1	0·943	309	095481	262	·019	·000361	·041	·028	·000784
2	1·164	088	007744	·321	143	·020449	·056	·013	·000169
3	1·002	250	062500	297	016	·000256	·029	·040	·001600
4	1·522	·270	072900	223	058	003364	·085	− ·016	·000256
5	1·969	717	091909	·326	045	002025	·136	− ·067	·004489
6	0·912	340	115600	259	·022	·000484	.	..	..

value of 't' as 8·333 while 't' at 1% level for 9 degrees freedom is 3·250 and for *Nereis chilkaensis* and *Perinereis nuntia* the value of 't' is 5·436. So the hypothesis that there may not be any such differences in the corresponding values for the species can be rejected. From the above it seems justifiable to conclude that the nephridium in *Lycastis indica* is comparatively larger in size than that of *Nereis chilkaensis* and *Perinereis nuntia*.

5. DISCUSSION.

The differences in the size and blood supply of the nephridia of the above three species of Nereidae, are significant and can probably be explained with reference to their habitat. It has been seen that *Lycastis indica* though found in fresh water is able to live in waters of high salinity. *Nereis chilkaensis* shows a more restricted range of distribution. It can withstand a certain amount of dilution of the external medium enabling it to thrive in brackish water, while *Perinereis nuntia* is a purely marine species.

The question is how far the differences noted in the nephridia of these species are related to their ability to withstand variations in salinity of the external medium. The importance of excretory organs in enabling marine species to survive a lowering of salinity of the surrounding water is suggested by Beadle (1937) from his experiments on *Nereis diversicolor* in which circumstantial evidence points to an elimination by the nephridia of a fluid hypotonic to body fluids. In *Sabella pavonina* which can survive low salinity conditions Ewer and Ewer (1943) have shown the importance of the thoracic nephridia in osmoregulation as seen from the fact that while the normal worms regain their original weight when transferred to diluted media, those in which the thoracic nephridia have been removed failed to recover. In the light of the above instances it is likely that in *Lycastis indica* the nephridia function in osmoregulation in enabling the animal to thrive in brackish and fresh water. In this connection the observation of Grobben (1881) that the nephridia of fresh water annelids are comparatively larger than those of their equal sized relatives confined to the sea, appears to be significant. Similar differences in the relative sizes of the antennary glands of the fresh water amphipod *Gammarus pulex* and the marine *Gammarus locusta* have been observed by Schwabe (1933) who correlated the larger size of the gland in fresh water species with its importance in osmoregulation. The significance of the increase in size of the excretory organs in fresh water species would appear to be related to the need for the excretion of large quantities of water entering the body along the osmotic

gradient. That the nephridia eliminate water entering the body from the external medium is evident from the work of Bahl (1945) who showed that the urine produced by the earthworm *Pheretima posthuma* when kept in water comes largely from the water absorbed through the skin. It would appear, therefore, that when marine species penetrate to brackish and fresh water there is likely to be a copious production of urine due to an increased influx of water and a large sized excretory organ would be advantageous in the elimination of increased quantities of water entering the body. It appears reasonable to regard the relatively larger size of the nephridium of *Lycastis indica* as an adaptation for life in fresh and brackish water and the differences in the relative sizes of the nephridium of *Lycastis indica*, *Nereis chilkaensis* and *Perinereis nuntia* may be correlated with their relative ability to withstand low salinity conditions.

Similarly the differences in the vascularisation of the nephridia in the three species studied, appear to bear a relation to their habits. It is seen from the work of Bahl (1945) that the mechanism of excretion of the nephridium in the earthworm is similar to that of the vertebrate kidney involving filtration, reabsorption and chemical transformation. Picken (1936) has pointed out that in the crayfish and *Peripatus* there is a preliminary filtration from the blood to the nephridium, the process being assisted by the hydrostatic pressure of the blood. The amount and nature of blood-supply of the nephridium in *Lycastis indica* suggest that a filtration of fluid might take place from the blood into the lumen of the nephridial canal. Since nephridia appear to be intimately associated with the water balance it is probable that the differences in vascularisation observed in *Lycastis* and *Nereis* are related to the adaptations necessary to maintain an osmotic equilibrium with the external medium. *Lycastis indica* which normally inhabits fresh water probably excretes a relatively large quantity of water. The richer capillary supply to the nephridium would afford an advantageous juxtaposition of the blood in relation to the nephridial canal and facilitate the excretion of large quantities of water. The underlying assumption is that there takes place a filtration of fluid from the blood into the lumen of the nephridium. On this basis, the comparatively poor vascularisation in *Nereis chilkaensis* might be related to its marine habitat and the water cycle associated with such an environment. It would appear that in sea-water which is in osmotic equilibrium with the body fluids, a smaller quantity of water is excreted. This is suggested by another consideration. It has been observed that the blood supply to the nephridium undergoes a marked diminution when *Lycastis indica* is acclimatised to sea-water. The condition of the blood supply in *Perinereis nuntia* which is marine, is what might be expected in the light of the above observations. If the filtration theory is assumed the repeated branching of the capillaries in the nephridium of *Lycastis indica* renders the filtering surface extensive to facilitate a rapid and profuse excretion. It has also been seen that a feature of the blood supply to the nephridium in *Lycastis indica* is the occurrence of dilatations on the capillaries. Although their functional significance is not clear the presence of similar structures in Oligochaetes could be considered as indicating an adaptation for life in an 'Oligochaete medium'. Between the extremes of freshwater type of nephridium represented by *Lycastis indica* and a typical marine type as seen in *Perinereis nuntia*, intermediate types might be expected. Such a one is seen in *Nereis chilkaensis* which is a marine species capable of invading brackish water.

The differences in the size and the nature and amount of blood supply of the nephridium of *Lycastis* and *Nereis* are significant when considered in the light of the habits and distribution of these two genera. *Nereis* is essentially a marine genus though there are a few exceptions. The genus *Lycastis* comprises fourteen species so far known. Of these only the type species *Lycastis brevicornis* (recorded from the west coast of France) appears to be purely marine. Curiously enough this species has not been re-discovered. All the other known species are found in

brackish and fresh water or show a great tolerance to changes in salinity of the external medium. From the distribution of the genus it is clear that the various species are confined to tropical regions thus suggesting a close correlation between the habits of the genus and the structural adaptations in the nephridia as understood from an examination of *Lycastis indica*.

6. Summary.

1. The nephridia of three species of Nereidae taken from waters of different salinities, were studied. *Lycastis indica* is found in brackish and fresh water, *Nereis chilkaensis* in brackish water and the sea, and *Perinereis nuntia* is purely marine.

2. The nephridia of *Lycastis indica* lie in the body-cavity on either side of the gut: they are comparatively larger in size than those of the other two species. The nephridial canal is disposed in the form of loops and is considerably lengthened. The vascular supply is pronounced. The features in the blood supply are: (1) the occurrence of blood capillaries within the connective tissue surrounding the lumen of the distal part of the nephridial canal and (2) the presence of dilatations of the blood capillaries.

3. The nephridia of *Nereis chilkaensis* lie at the entrance to the parapodial cavity. The body of the nephridium is compact and smaller in size. It is formed of connective tissue through which runs a coiled nephridial canal. The blood-supply to the nephridium is not so rich as in *Lycastis indica*. The capillaries lie on the outside of the body of the nephridium.

4. The nephridia of *Perinereis nuntia* are comparatively smaller in size than those of the other two species and the nephridial blood vessels are poorly developed.

5. In specimens of *Lycastis* acclimatised to sea-water the blood supply to the nephridium undergoes a diminution as seen from the shrunken condition of the blood capillaries of the nephridium.

6. The nephridia of the three species examined above are compared and the variations in size and vascularisation are discussed in the light of their probable relation to osmoregulation.

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8. Explanation of Photomicrographs.

Fig. 1. A section through the body of the nephridium of *Lycastis indica*.
Fig. 2. A section passing through a different plane, of the nephridium in *Lycastis indica*.
Fig. 3. A section of the nephridium of *L. indica* which has been acclimatised to sea water showing the condition of the blood capillaries.

9. Key to Lettering.

A	.. Dilatations of the capillaries.
BL	.. Boundary layer.
BL.V	.. Blood vessel.
CIL	.. Cilia.
CIL.PROC	.. Ciliated processes of the nephridiostome.
COEL.EP	.. Coelomic Epithelium.
EP	.. Ectoderm.
EXT.CIL	.. External cilia of the nephridiostome.
F	.. Fibrillae.
INT.CIL	.. Internal cilia of the nephridiostome.
L.P	.. Lip of the nephridiostome.
L.N.C	.. Lumen of the nephridial canal.
LUF	.. Lumen of the nephridiostome.
N	.. Nucleus.
N′	.. Nucleus of the connective tissue cell.
NE.C	.. Nephridial canal.
NEP	.. Nephridioporo.
NET	.. Connective tissue.
WF	.. Wall of the nephridiostome.
V	.. Vacuoles in the connective tissue of the nephridium.

* Not referred to in original.

EFFECT OF ORGANIC MANURES ON THE OXYGEN BUDGET IN FISH PONDS.

By T. R. BHASKARAN, *All-India Institute of Hygiene and Public Health, Calcutta.*

(Communicated by Dr. S. L. Hora, F.N.I.)

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The dangers of manuring water with heavy doses of sewage and other organic materials are not unknown to pisciculturists. A typical instance of large scale fish mortality due to over application of organic manure was witnessed by us recently in the Hanakhali sewage-irrigated fishery near Calcutta. This provided an opportunity for studying the effects of organic fertilisers on fish productivity in general and the attendant physico-chemical aspects related to sewage fisheries. While the results of this investigation will form the subject of a separate communication by Mr. S. P. Basu, the main object in presenting this paper is to point out some of the fundamental aspects of the question about which we have meagre data and to emphasise the need for more experimental work, taking into account the recent advances in our knowledge in the field of water sanitation.

Oxygen is important for all life and the resources of oxygen in the aquatic environment are indeed very limited. This condition often becomes a critical factor in tropical ponds because of the low rate of re-aeration and large consumption of oxygen required for biochemical oxidation. Application of organic fertilisers to fish ponds should, therefore, be done with due regard to this consideration. Injudicious application of organic fertiliser to water will lead to hazardous oxygen condition often leading to large scale mortality of fishes.

The chief source of dissolved oxygen in the aquatic environment is the atmosphere and the rate of oxygenation of any body of water is dependent on the nature of its source and the temperature. Rapid circulation of water taking place in tropical ponds and lakes helps the process of re-aeration considerably. When there is good sunlight, the plant life in water also contributes towards its oxygen resources. The oxygen thus made available in the body of water is made use of by the organisms for respiration. A considerable portion of the dissolved oxygen is also utilised for the biochemical oxidation of the organic materials present in the body of water as well as in the bottom sediments. A satisfactory balancing of the income and expenditure of oxygen within the water environment is essential for the sustenance of healthy fish life. Even under the most unfavourable weather conditions the oxygen concentration should not fall below 3 parts per million of oxygen, the minimum required for healthy fish life (U.S. Pub. Health Report, 1943). An understanding of the oxygen transactions taking place inside the water body to which various organic fertilisers are added is, therefore, fundamental in standardising fertiliser practices.

The nature of the oxygen transactions taking place in a pond fertilised with organic manures can best be discussed by considering a specific instance of a small pond fertilised with sewage. If the pond is to sustain healthy fish life, the application of sewage should be limited to a dose such that the concentration of

oxygen in the pond water does not fall below 3 p.p.m. (2·14 c.c. per litre). Let us now consider a small pond 200 feet by 100 feet with an average depth of 5 feet of water. At 85 per cent saturation level, the water in the pond will hold 42 lbs. of oxygen at a temperature of 25°C. The re-aeration constant of this pond may be assumed to have a value of 0·05 per day at 25°C (Streeter, 1926). Under these conditions it can be shown that re-aeration will provide 23 lbs. of oxygen to the pond water every day. The total amount of oxygen available in the pond will, therefore, be of the order of 42 + 23 = 65 lbs. Leaving 3 p.p.m. (19 lbs.) of oxygen in the pond water, we have 65 − 19 = 46 lbs. of oxygen available for biochemical oxidation of the organic manure. The application of sewage to the pond should be limited to this oxygen consumption in a single day.

The rate at which oxygen is consumed for biochemical oxidation of sewage and other organic matter follows what the chemist calls the unimolecular law (Thomault, 1926). This law states that the amount of oxygen used up during any period is proportional to the concentration of organic matter at the beginning of the period. The biochemical oxygen consumption rate of sewage in the pond environment is of the order of 0·125 per day and this represents 25 per cent of biochemical oxygen consumption in the course of each day. It has been shown that the maximum oxygen available in a single day that can be used up for biochemical oxidation of organic matter is 46 lbs. From the above it would be apparent that $46 \times \frac{100}{25} = 184$ lbs. of sewage as B.O.D. can be safely applied to the pond. If this amount of sewage is added to pond, the oxygen consumption in the pond will be as follows:—

1st day	46 lbs.	4th day	25 lbs.
2nd day	36 ,,	5th day	18 ,,
3rd day	29 ,,	10th day	5·7 ,,
		20th day	0·7 ,,

After 20 days, a second dose of sewage may be applied and the operation repeated periodically without any deterioration in the oxygen status of the pond.

Knowing the biochemical oxygen consumption rate of the organic manure and the re-aeration constant of the body of water, it is possible, therefore, to figure out the dose of organic manure that can be safely applied to the pond. Temperature and other atmospheric conditions do affect the rate at which these oxygen transactions take place. But the value of the rate constants can be corrected to include these affects and the dosage of manure can be determined for the actual conditions obtaining in the pond.

Part of the organic manure settles in the bottom of the pond. The bottom sediments will also demand the oxygen resources in the water for their decomposition. However, the rate of biochemical oxidation of the organic matter in the pond bed is very low, being of the order of ·005 per day and if the bed is not vigorously disturbed the demands made by the bottom sediments are not very considerable.

Some data are available in literature on the re-aeration constants of different bodies of water (Phelps, 1948). They are as follows:—Small ponds ·05 to 0·1 per day, sluggish streams 0·1 to 0·2 per day, normal streams of low velocity 0·2 to 0·3 per day and swift streams 0·3 to 0·5 per day. The rate constant for biochemical oxygen consumption of sewage in the aquatic environment is known, but a similar data on other organic fertilisers are not available.

Photosynthetic activity of plants, under certain conditions, will add considerable amounts of oxygen to the pond. This is somewhat undependable. An appraisal of the oxygen assets contributed by them is not possible because we have few quantitative data on the oxygen donating power of the green plants growing in water. Too much growth of algae or other green plants is not desirable as they

will use up considerable amounts of oxygen from the water during the night and cloudy part of the days. More experimental data on this aspect of the problem is necessary before we can intelligently use algae and green plants as an aid in maintaining the oxygen balance in fish ponds.

Application of organic manures to fish ponds affects the oxygen balance in the pond environment. If manuring practices are to be rationalized on the basis of the oxygen requirements, there is need for more specific data on (i) rate of biochemical oxygen consumption of different types of organic manures, such as cow dung, sheep manure, oil cakes, etc., which are commonly used in fish farming and (ii) oxygen donating power of different types of plant associations met with in fresh waters.

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STUDIES ON CYTOCHEMISTRY OF HORMONE ACTION.

PART XI. THE DISTRIBUTION OF ASCORBIC ACID IN THE ADRENAL CORTEX OF NORMAL AND ESTROGEN-TREATED PIGEONS.

By AMIYA B. KAR, *Senior Research Fellow, N.I.S.I., and* ASOK GHOSH, *Central Drugs Laboratory, Government of India, Calcutta.*

(Communicated by Dr. B. Mukerji, F.N.I.)

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INTRODUCTION.

Brisk chemical investigations are making it increasingly evident that ascorbic acid is intimately associated with the secretion of steroid hormones by the adrenal cortex (Giroud and Ratismamanga, 1942; Sayers *et al.*, 1945; Ludewig and Chanutin, 1947; and others). Moreover, many substances including the estrogens (Masonyi, 1936; Mlinko, 1938) and the ACTH (Sayers *et al.*, 1946) are now known to reduce the adreno-cortical ascorbic acid. It is believed that this reduction in ascorbic acid level reflects the inability of the cortical cells to synthesise steroid hormones (Deane and Morse, 1948). Sayers and Sayers (1948) also regard the ascorbic acid level as an useful indicator of the secretory activities of the adrenal cortex. The important rôle of this vitamin in the adreno-cortical physiology therefore, appears to be well recognised and in view of this we decided to investigate cytochemically the distribution of ascorbic acid in the adrenal cortex, using not only normal animals but also animals that had been treated with estrogenic hormone. The pigeon served as our animal of choice since the cytochemical demonstration of ascorbic acid in the adrenal cortex of this species has not hitherto been reported.

In the mammalian adrenal cortex, cytochemical studies have revealed that large quantities of ascorbic acid uniformly occur in the cells of the fasciculata and the reticularis but is either absent or present in small quantities in the glomerular zone (Gough and Zilva, 1933; Bessey *et al.*, 1934; Bourne, 1934 and 1935; Westergaard, 1934; Giroud and Leblond, 1935*a* and *b*, 1936; Leblond and Gardner, 1938; Barnett and Bourne, 1940; Tuba *et al.*, 1946; Deane and Morse, 1948).

EXPERIMENTAL PROCEDURE.

Adult pigeons were used in this study. A total of 12 birds were used of which 6 were injected with estrogen and the remaining 6 were left uninjected to serve as the controls. All of the birds were kept in cages under uniform husbandry conditions throughout the duration of the experimental period. Estradiol dipropionate in sterile sesame oil was intramuscularly injected (2·5 mgm. or 25,000 dipropionate units daily) for a period of 10 days. The sites of injection alternated successive days between the right and left sides of the breast.

Autopsy followed 24 hours after the final injections. The animals were killed by a blow on the head in order to allow least possible ante-mortem trauma to the adrenal. The glands were fixed and processed according to the technique of Deane and Morse (1948) for the demonstration of ascorbic acid. The details of the technique as laid down by these authors were followed meticulously and only 50 seconds were allowed to elapse between killing an animal and placing the adrenal in the fixative. In order to make a critical observation of the silvered deposits

signifying a corbic acid or reducing substance of similar activity, no counterstain was used. The sections were dehydrated and mounted in the usual manner.

RESULTS.

Controls.—Before presenting our observations on the distribution of ascorbic acid in the pigeon's adrenal cortex, we propose to make a brief comment on the microscopic organisation of the avian adrenal cortex since it differs in many respects from that of the mammalian cortex. In these animals the cortical tissue is found throughout the gland in islands and amastomosing strands interspersed with groups of medullary cells. The cortical masses are usually larger at the periphery than in the centre of the gland. Between the strands of cortical and medullary tissue is an intricate network of capillaries. The detailed cytological and cytochemical features of the avian adrenal cortex have been described in papers by Miller and Riddle (1942) and by Kar (1947 *a* and *b*, 1950, 1951).

Following fixation with the acid silver nitrate-alcohol solution granules of precipitated silver indicating ascorbic acid or reducing activity as great as that of ascorbic acid are consistently encountered in the cytoplasm of the cortical cells. The granules are absent in the nuclei and their cytoplasmic distribution appears to be irregular (Pl. XI, fig. 1). In addition to their intracellular location, the silver precipitates also occur in the vascular sinusoids. The granules are mostly irregular in outline and appear fairly crowded in the cortical masses. The distribution of the silvered particles in the peripheral and central cortical masses are more or less uniform.

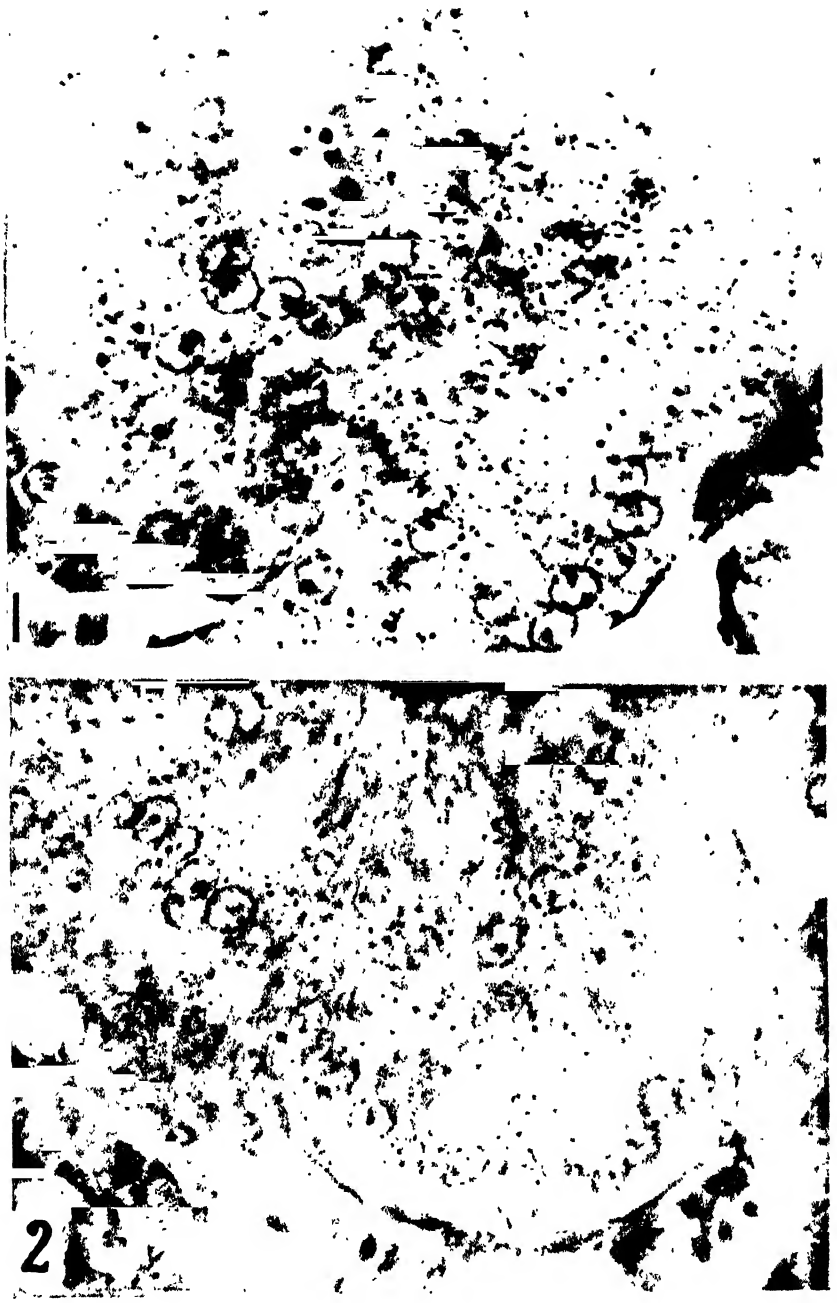
Estrogen treated.—There is a definite reduction in the amount of reduced silver in the cortex of the estrogen recipients. However, the gross pattern of distribution of the particles remains the same as in the controls. The silvered granules appear much finer and considerably sparser than in the controls (Pl. XI, fig. 2). In some cortical cells only a few particles are encountered. There is also a marked loss of the precipitated silver from the vascular sinusoids.

COMMENTARY.

The present studies have indicated clearly that ascorbic acid (or reducing substance of similar activity) is normally present in the parenchymal cells of the pigeon's adrenal cortex. Treatment with estrogenic hormone considerably depletes cortical ascorbic acid level. Our cytochemical findings, therefore, appear to be in agreement with the chemical observations of Mosonyi (1936) and Mlinko (1938) who reported a similar loss of ascorbic acid from the adrenal cortex after estrogen treatment. Moreover, in the light of the current concept that the decline in ascorbic acid level is associated with the inability of the cortical cells to synthesise steroid hormones (Deane and Morse, 1948), it would appear that estrogen treatment considerably affected steroid hormone production in the pigeon's adrenal cortex. However, we venture to make this speculation with considerable reservation, since according to Sayers and Sayers (1948), it has not been possible yet to decipher the precise rôle this vitamin plays in the series of reactions leading to the transformation of cholesterol into cortical hormone(s). In this connection, Lowenstein and Zwemer's unconfirmed report (1946) that the cortical steroid may exist as a conjugate of ascorbic acid appears to be suggestive, but until confirmation of this finding is available it would be unwise to speculate on its significance.

SUMMARY.

The distribution of ascorbic acid has been studied cytochemically in the adrenal cortex of the pigeon. Estrogen treatment considerably depletes adreno-cortical ascorbic acid. The significance of this vitaminic depletion is discussed.



(*All figures are photomicrographs and are magnified* × 700).

FIG. 1. Section through the adrenal gland of a control pigeon. Note the distribution of ascorbic acid in the form of dark granules.

„ 2. Section through the adrenal gland of an estrogen treated pigeon. Ascorbic acid is markedly reduced in amount. The granules appear finer and sparser than in the control animals.

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A NOTE ON THE RELATION BETWEEN MAXIMUM PRESSURE AND SHOT-START-PRESSURE.

By N. S. VENKATESAN, *Defence Science Organisation, Ministry of Defence, New Delhi.*

(Communicated by Dr. R. S. Varma, F.N.I.)

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1. INTRODUCTION.

The three main problems of Internal Ballistics are to obtain, for given loading conditions in a gun, (i) the pressure-space curve, (ii) the maximum pressure, and (iii) the muzzle velocity. The pressure-space curve is mainly used in designing the gun and is not usually required very accurately, since factors of safety are applied in the calculation of gun-stresses. The maximum pressure and the muzzle velocity are generally required to a greater degree of accuracy. Various methods have been devised for the integration of the equations of internal ballistics so as to produce solutions which may be tabulated. One of the points of difference between the several methods relates to the nature of the initial conditions. The shot does not begin to move immediately after the ignition of the charge; initially the charge burns under closed vessel conditions and the pressure rises until it is sufficient to cause the driving band to be engraved by the rifling. Since the velocity of the shot and the increase in chamber capacity during the engraving are small, it is a reasonable idealisation to assume that the shot remains at rest until the pressure reaches a certain value (the 'shot-start-pressure'). This is the basis of the Hunt-Hinds system (1951) of which a slightly different version was given subsequently by Goldie (Corner, 1950). Not much physical significance can be attached to the shot-start-pressure; it represents merely one way of simplifying the mathematical treatment of the otherwise complex process of band engraving and also (in some methods of approximation) the effect of bore resistance on the shot. In fact, there are systems of internal ballistics which ignore the shot-start-pressure altogether and take account of the resistance due to band engraving by adjusting suitably the rate of burning. The value of the shot-start-pressure is usually of the order of 2 tons/sq. in., if heat loss and frictional resistance to motion are otherwise allowed for.

The integration of the equations of internal ballistics in their general form, even with certain simplifying assumptions as explained above, is a matter of considerable difficulty, involving in general a process of step-by-step numerical solution or the use of a differential analyser. With a view to gain some insight into the effect of shot-start-pressure on the maximum pressure, we consider in this paper the problem under certain further simplifying assumptions, which enable the equations to be solved easily without, however, sacrificing the essential features of the general case. The following assumptions are made :—

(i) We take $\theta = 0$.

(ii) We neglect covolume correction, i.e. $B = 0$.

The first assumption implies that the propellant is tubular, which is the form most commonly used *. The second assumption is equivalent to assuming that

* There is a decided advantage in using tube or multi-tube propellants, since this enables a reduction in maximum pressure with only a small reduction in muzzle velocity.

the covolume of the gases equals the reciprocal of the density of the solid propellant. This is generally true except at high densities of loading.

With these assumptions, the equations have been solved and an explicit expression for the relation between the maximum pressure and shot-start-pressure has been derived.

2. Basic Equations.

The equations for determining the various ballistic quantities such as the maximum pressure, the muzzle velocity, position of 'burnt', etc., are the following :—

(i) Energy Equation.
(ii) Dynamical Equation (Motion of the shot).
(iii) Equation for rate of burning.
(iv) Expression for the form function.

(i) *Energy Equation.*

This equation is simply the expression of the principle of Conservation of Energy : the sum total of the energies useful (K.E. of shot) and wasted (thermal and kinetic energy of gases, heat loss to barrel, etc.) must be equal to the chemical energy of the propellant. With any propellant are associated two constants, viz. the force-constant F and the ratio of the specific heats γ :—

$$F = nRT_0$$

$$\gamma - 1 = nR/J\sigma_v$$

where
T_0 temperature (in degrees absolute) at which gases are evolved.
R universal gas constant.
$1/n$ molecular weight.
J = mechanical equivalent of heat.
σ_v specific heat at constant volume.

Thus $J\sigma_v T_0 = \dfrac{F}{\gamma - 1}$ is the energy available from a unit mass of propellant. If C be the mass of the total charge and z the fraction of charge burnt at any time, the amount of energy supplied to the gun is

$$FCz/(\gamma - 1).$$

On the other hand, we have—

Kinetic energy of shot $= \frac{1}{2}mv^2$,
Thermal energy of gases $= J\sigma_v TCz$.

(T is the mean temperature of gases.)
and the Kinetic energy of gases $\frac{1}{6}Cv^2$.*

* To see this, we assume, as a reasonable approximation, that the velocity of the gas at any point is proportional to the distance from the breech :

$$v_x = kx$$

Hence, if ρ is the mean density and A is the cross-sectional area of the bore the K.E. of gases $= \int_0^x \frac{1}{2} A\rho \cdot v_x^2 \, dx = \frac{1}{2} A\rho \cdot k^2 \frac{x^3}{3} = \frac{1}{6} Cxv^2$.

But since this itself is a correction term, we take $x = 1$ and the K.E. of the gases $= \frac{1}{6}Cv^2$

The loss due to frictional resistance is taken as 4% of the K.E. of the shot and the heat loss to the barrel as 2% thereof.

Thus we have

$$\frac{FCz}{\gamma-1} = J\sigma_v TCz + \tfrac{1}{2}w_1v^2 \quad .. \quad .. \quad .. \quad .. \quad (1)$$

where $w_1 = 1{\cdot}06w + \frac{1}{3}C.$

The Noble-Abel equation of state applied to the gas in the chamber gives

$$P\left[K_0 + Ax - \frac{C(1-z)}{\delta} - Czb\right] = nRT \quad .. \quad .. \quad .. \quad .. \quad (2)$$

where P = mean pressure in the chamber.
K_0 = chamber capacity.
δ = density of solid propellant
b = covolume.

If we write

$$\left.\begin{aligned} K_0 - \frac{C}{\delta} &= Al \\ \frac{C}{Al}\left(b - \frac{1}{\delta}\right) &= B \end{aligned}\right\} \quad .. \quad .. \quad .. \quad .. \quad (3)$$

and eliminate T between (1) and (2) we get

$$\frac{FCz}{Al} = P\left(1 + \frac{x}{l} - Bz\right) + \tfrac{1}{2}\frac{\gamma-1}{Al}w_1v^2 \quad .. \quad .. \quad .. \quad .. \quad (4)$$

(ii) *The Dynamical Equation.*

This is obtained by applying Newton's Second Law to the motion of the shot :

$$w_1v\frac{dv}{dx} = AP \quad .. \quad .. \quad .. \quad .. \quad .. \quad (5)$$

(iii) *Equation of Rate of Burning.*

$$D\frac{df}{dt} = -\beta' P^{\alpha}$$

Here D is the 'web-size' or the least dimension of the propellant grain and f the fraction thereof remaining unburnt at time t. The exponent α is usually not far from unity. By adjusting β', we may put $\alpha = 1$ (linear rate of burning) :

$$D\frac{df}{dt} = -\beta P \quad .. \quad .. \quad .. \quad .. \quad (6)$$

(iv) *Equation for the form function.*

Assuming parallel law of burning and simultaneous ignition over all the burning surface, we can write, for most of the propellants in service use,

$$z = (1-f)(1+\theta f) \quad .. \quad .. \quad .. \quad .. \quad (7)$$

where θ is a constant depending on the shape of the propellant grain.

3. Solution of the Equations.

We first express our equations in terms of non-dimensional variables by the following usual substitutions :—

$$\left.\begin{aligned} \xi &= 1+\frac{x}{l} \\ \eta &= \frac{AD}{F\beta C}v \\ \zeta &= \frac{Al}{FC}P \\ M &= \frac{A^2D^2}{F\beta^2 C m_1} \end{aligned}\right\} \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (8)$$

With these our equations become :

$$z = \zeta(\xi - BZ) + \frac{\gamma-1}{2M}\eta^2 \quad \ldots\ \ldots\ \ldots\ \ldots \quad (9)$$

$$M\zeta = \eta\frac{d\eta}{d\xi} \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (10)$$

$$\zeta = -\eta\frac{df}{d\xi} \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (11)$$

$$z = (1-f)(1+\theta f) \quad \ldots\ \ldots\ \ldots \quad (12)$$

We now introduce the assumptions :

$$\theta = 0\ ;\ B = 0 \quad \ldots\ \ldots \quad (13)$$

The initial conditions at the shot-start are

$$\xi = 1\ ;\ \eta = 0\ ;\ \zeta = \zeta_0\ ;\ z = z_0 \quad \ldots\ \ldots\ \ldots \quad (14)$$

From (9) we see that

$$z_0 = \zeta_0 \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (15)$$

so that z_0 itself is a measure of the shot-start pressure. Introducing (13), the equations (9)–(12) become :

$$z = \zeta\xi + \frac{\gamma-1}{2M}\eta^2, \quad \ldots\ \ldots\ \ldots\ \ldots \quad (I)$$

$$M\zeta = \eta\frac{d\eta}{d\xi}, \quad \ldots\ \ldots\ \ldots\ \ldots \quad (II)$$

$$\zeta = -\eta\frac{df}{d\xi}, \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (III)$$

$$z = 1-f \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (IV)$$

From (II), (III) and (IV) we obtain :

$$\eta = M(z-z_0) \quad \ldots\ \ldots\ \ldots\ \ldots \quad (16)$$

Substitution of this in (I) yields

$$\frac{2\eta\,d\eta}{2Mz_0+2\eta-(\gamma-1)\eta^2} = \frac{d\xi}{\xi} \quad \ldots\ \ldots\ \ldots\ \ldots \quad (17)$$

whence, integrating and using the initial conditions, we get

$$\xi^{\gamma-1}\left[2Mz_0+2\eta-(\gamma-1)\eta^2\right]=2Mz_0\left[\frac{K+\frac{1}{\gamma-1}}{K-\frac{1}{\gamma-1}}\right]^{\frac{1}{K(\gamma-1)}}\left[\frac{K+\eta-\frac{1}{\gamma-1}}{K-\eta+\frac{1}{\gamma-1}}\right]^{\frac{1}{K(\gamma-1)}} \quad .. \quad .. \quad .. \quad (V)$$

where $$K=\sqrt{\left\{\frac{1}{\gamma-1}\left(2Mz_0+\frac{1}{\gamma-1}\right)\right\}}$$

so that, from (II), (17) and (V), we have

$$\zeta=\frac{\left[2Mz_0+2\eta-(\gamma-1)\eta^2\right]^{\frac{\gamma}{\gamma-1}}}{2M\left[2Mz_0\left(\frac{1+K_1\eta}{1-K_2\eta}\right)^{\frac{1}{K(\gamma-1)}}\right]^{\frac{\gamma}{\gamma-1}}} \quad .. \quad .. \quad .. \quad (VI)$$

with $K_1=\dfrac{1}{K-\frac{1}{\gamma-1}}$; $K_2=\dfrac{1}{K+\frac{1}{\gamma-1}}$

The expression (VI) for ζ can also be written as

$$\zeta=\frac{1}{2M}\cdot\frac{2Mz_0+2\eta-(\gamma-1)\eta^2}{\xi} \quad .. \quad .. \quad .. \quad (18)$$

For maximum pressure, $\dfrac{d\xi}{d\eta}=0$, and from (18) this gives

$$\eta=\eta_1=\frac{1}{\gamma} \quad .. \quad .. \quad .. \quad .. \quad (19)$$

Hence,

Maximum pressure $$\zeta_1=\frac{2Mz_0+2\eta_1-(\gamma-1)\eta_1^2}{2M\xi_1} \quad .. \quad .. \quad .. \quad .. \quad (20)$$

where ξ_1 is given by (V), by putting $\eta=\eta_1$.

By using the fact that z_0 is small and expanding all the quantities in power of z_0, we obtain, after some tedious algebra, the following expansion for ζ_1 :

$$\zeta_1=\left\{\frac{\gamma+1}{2M\gamma^2 b_0{}^{1/\gamma}}\right\}^{\frac{\gamma}{\gamma-1}} z_0^{\left[-Mz_0+\frac{1}{4}M^2z_0^2(\gamma-1)\right]}$$

$$\times\left[1+z_0\left\{M\log b_0-\frac{a_0'}{\gamma-1}\right\}+\frac{z_0^2}{2}\left\{(\log b_0)^2-3M^2(\gamma-1)\log b_0+\frac{a_0'^2\gamma}{(\gamma-1)^2}-\frac{2a_1'}{\gamma-1}\right\}+\ldots\right] \quad .. \quad (VII)$$

where

$$a_0 = \frac{2(\gamma^2+2\gamma-2)}{(\gamma+1)^2}, \qquad a_0' = \frac{a_0}{b_0}.$$

$$a_1 = \frac{(\gamma^2+6\gamma+1)(\gamma-1)^2 M}{2(\gamma+1)^3}, \quad a_1' = \frac{a_1}{b_0}.$$

$$b_0 = \frac{2}{M(\gamma+1)}$$

By means of the expression (VII), values of ζ_1 can be tabulated against values of ζ_0 and M. A double entry table worked out thus is given below. The values of M and ζ_0 are chosen with a view to what is actually obtained in practice. It must be noted that there is a limitation on the value of M. At the position of maximum pressure,

$$\eta_1 = M(\zeta - \zeta_0),$$

so that $\zeta_1 = \zeta_0 + \frac{\eta_1}{M}$

$$= \zeta_0 + \frac{1}{\gamma M}.$$

Since $\zeta_1 < 1$, we must have

$$\frac{1}{\gamma M} + \zeta_0 < 1$$

or,
$$M > \frac{1}{\gamma(1-\zeta_0)}$$

The values of M chosen here satisfy this condition. For values of M less than this value, the max. pressure occurs at 'all burnt' position.

ζ_0 \ M	1	2	3	4	5
0·00	0·3099	0·1550	0·1033	0·0775	0·0620
0·02	0·3479	0·1899	0·1368	0·1040	0·0898
0·03	0·3616	0·2052	0·1450	0·1167	0·0996
0·04	0·3798	0·2079	0·1556	0·1290	0·1108
0·05	0·3928	0·2245	0·1660	0·1385	0·1228

A glance at the table shows that the maximum pressure increases as the shot-start-pressure increases but decreases as M increases. It will be seen that

an increase in M can be effected by increasing A or D or decreasing F, β or C, but we must take care that in making such changes, the muzzle velocity is not adversely affected.

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Summary.

Neglecting the covolume correction and taking the propellant to be tubular, the equations of the interior ballistics of a conventional gun are integrated and an explicit relation between the maximum pressure and the shot-start-pressure is derived. The variation of maximum pressure with shot-start-pressure and the central ballistic parameter is illustrated by a table of numerical values derived from the above solution.

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STUDIES ON SOUTH INDIAN FUSARIA.

I. FUSARIUM VASINFECTUM ATK., WITH A NOTE ON ITS VARIETIES AND FORMS.

By C. V. SUBRAMANIAN, *University Botany Laboratory, Madras.*

(Communicated by Dr. M. O. P. Iyengar, F.N.I.)

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During a study of the wilt disease of cotton in South India the author was able to isolate from wilted cotton plants and from 'wilt-sick' soil a large number of Fusaria which required identification. Preliminary work indicated that a number of these isolates belonging to the section *Elegans* appeared to be identical with *Fusarium vasinfectum* Atk. or its varieties or forms as set forth in the classification of Wollenweber and Reinking (1935). [Snyder and Hansen's proposals (Snyder and Hansen, 1940) have many difficulties in the way of their general acceptance.] Detailed study, however, was necessary to settle the identity of the various isolates. Representative isolates from soils and wilted cotton plants were therefore compared with cultures of *F. vasinfectum* and its varieties and forms obtained from the Centraalbureau voor Schimmelcultures, Baarn, Holland.

Comparisons made between the author's isolates and those obtained from Baarn were in respect of the following: (i) morphology, mainly spore shape, size, etc.; (ii) cultural characters, mainly colour; (iii) growth rate in standard media; and (iv) pathogenicity to cotton plants. The results form the subject matter of the present communication.

METHODS.

Altogether seven representative single spore isolates were chosen for the present investigation. Of these, S 7 and S 21 were isolated by the author from 'wilt-sick' cotton soil from Udamalpet (Coimbatore District, Madras State) using the root burial technique (Subramanian, 1946); S 17, S 19, S 20A, S 20B and S 20C were from vascular systems of wilted cotton plants collected from Udamalpet. The following cultures obtained from the Centraalbureau voor Schimmelcultures were also included for purposes of comparison: *Fusarium vasinfectum*, *F. vasinfectum* f.1, *F. vasinfectum* f.2, *F. vasinfectum* v. *latulatum*, *F. vasinfectum* v. *zonatum*, *F. vasinfectum* v. *zonatum* f.1, and *F. vasinfectum* v. *zonatum* f.2.

Standard mycological technique was employed throughout the investigation.

The need for using a number of different media in studies on the genus *Fusarium* has been emphasised by many workers. The object of this recommendation is primarily to bring isolates, where necessary, to a state of 'hochkultur' suitable for study. No difficulty was experienced in bringing the present isolates to a state of 'hochkultur' since all of them sporulated satisfactorily on oatmeal agar. This medium was therefore used to study spore shape and size in the case of the various isolates. Steamed rice prepared according to Leonian (1929) was used to ascertain colour production by the various isolates. In recording observations on colour, Maerz and Paul's (1930) 'Dictionary of Color' was used. The numbers used in Tables 2 and 3 refer to the numerical designations attached to different colours in Maerz and Paul's Color charts.

Methods followed in pathogenicity tests were as follows: the inoculum in each case consisted of the fungus grown for four weeks in sterilised garden soil + 2 %

powdered Quaker oats + modified Shive's* solution. Inoculum was mixed with partially sterilised garden soil (saturation capacity 30 %) in the proportion of 10%, and 480 g. of the mixture were weighed into each pot. Control pots had sterilised garden soil + 2% powdered Quaker oats + modified Shive's solution, without any fungus, mixed with partially sterilised garden soil in the proportion of 10%. Seeds of susceptible K. 2 variety of cotton (*Gossypium arboreum* v. *neglectum* f. *indica*) were sown six per pot after delinting with concentrated sulphuric acid and surface sterilisation with 1/1,000 aqueous mercuric chloride. There were twenty-five such pots for each isolate. Moisture level of soils in pots was maintained approximately at 50 60 % of saturation capacity. Plants were under observation for over nine weeks. Infected plants were plated out on acidified potato dextrose agar and the fungi growing out compared with the isolates used for inoculation in each case.

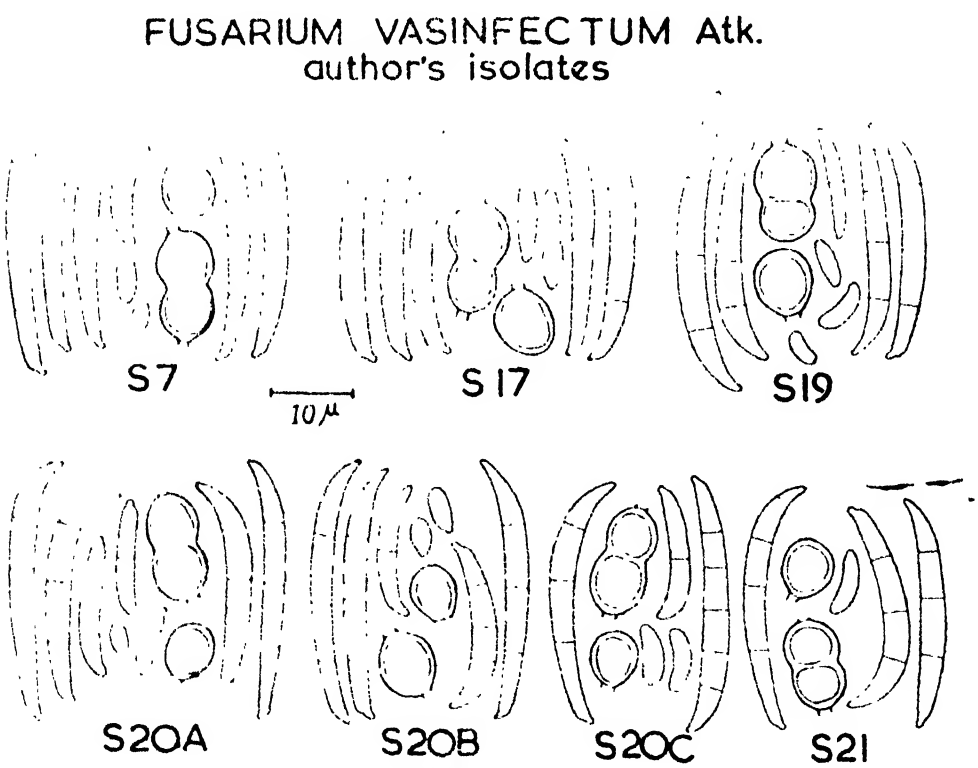
Results.

Morphology and Cultural Characters.

Observations regarding the formation of sporodochia, pionnotes, sclerotia, etc. by the isolates studied in four different media, viz., oatmeal agar, potato dextrose agar, sterilised pigeon pea stems and steamed rice at two temperatures (20° and 30°C.) are given below :—

(1) Typical sporodochia were produced only by isolates S 7, S 20B and cultures of *F. vasinfectum* v. *intelatum* and *F. vasinfectum* v. *zonatum* f.1.

(2) All isolates and cultures studied developed pionnotes on oatmeal agar.



Text-fig. 1.

* Modified Shive's solution conforms to the following specification: prepared according to McLean and Cook (1941) with addition of 1·0% sugar.

TABLE 1.

Measurements (in microns) of conidia and chlamydospores of the author's isolates of Fusaria grown on oatmeal agar for 21 days at room temperature (30°C.).

Isolate.	Conidia.						Chlamydospores.			
	0-septate.		1-septate.		3-septate.		1-celled.*		2-celled.	
	Mean.	Range.	Mean.	Range.	Mean.	Range.	Mean.	Range.	Mean.	Range.
S 7 ..	8×2·5	(4–12×1–4)	13×2·8	(9–19×2–4)	32×3·3	(26–39×2–5)	8·7	(6–12)	12×8	(10–15×6–9)
S 17 ..	8×2·4	(4–12×1–4)	13×2·8	(8–17×2–4)	31×3·4	(24–39×3–5)	8·7	(6–12)	13×8	(11–15×6–10)
S 19 ..	8×2·5	(4–14×1–4)	13×2·8	(8–19×2–4)	32×3·4	(24–40×2–5)	9·4	(6–12)	12×8	(10–14×6–9)
S 20A ..	8×2·4	(4–14×1–4)	12×2·7	(6–17×1–4)	30×3·4	(21–39×2–5)	8·5	(5–10)	13×9	(9–15×7–10)
S 20B ..	8×2·5	(3–12×1–4)	15×2·7	(9–20×1–4)	33×3·2	(26–40×2–5)	8·7	(6–12)	12×8	(10–15×6–10)
S 20C ..	9×2·5	(4–14×1–4)	14×3	(8–19×2–4)	32×3·5	(26–37×3–5)	8·7	(6–12)	12×8	(10–14×7–9)
S 21 ..	9×2·9	(4–14×1–4)	13×2·8	(8–19×2–4)	32×3·6	(25–37×3–5)	8·6	(6–12)	12×8	(10–14×6–10)

* Measurements refer to the diameter.

TABLE 2.

Showing cultural characters of author's cultures of Fusaria grown on steamed rice incubated at 30° C.

Fungus.	11 days.	21 days.	30 days.
S 7	Aerial mycelium abundant, cottony, white on top of slant, but coloured below with following: 41 B 2, 41 C 1, 43 D 1, 43 C 2, 43 C 3 (Ageratum blue), 44 F 4 (Vestal), 45 G 5 (Crushed violets), 46 I 5 (Oto mauve), 47 J 5.	Unchanged. Coloured with following shades of rose, pink and violet: 3 A 9 (Sandust-variety), 3 G 1 (Corinthian Pk.), 6 D 3 (Livid Br.), 46 H 1, 47 J 2 (Indian purple).	Unchanged. Colour same as at the end of 21 days.
S 17	Aerial mycelium abundant, white cottony on top of slant but just below coloured with following: 1 C 2 (Peach blossom), 2 G 8 (Rose leaf), 3 F 3 (Bridal rose), 45 I 6 (Livid Pr.).	Growth fluffy, compact and not cottony, pale white on top. Coloured predominantly pink, with following shades: 1 B 1 to 1 C 2 (Peach blossom) to 1 E 3 to 2 G 2 to 2 I 2 (Rose Marie) to 3 G 1 (Corinthian Pk.) to 5 E 3 (Nectar) to 6 D 3 (Livid Br.) Also shades of 43 C 3 (Ageratum blue).	Unchanged. Colours same as at the end of 21 days.
S 19	Aerial mycelium abundant, cottony and of a 3 A 2 colour on top and below coloured with following shades: 3 D 2, 3 F 3 (Bridal rose), 3 I 2 (Vassar rose), 3 J 8 (Tango Pk.) 4 I 8 (Colonial rose), 47 H 6.	Mycelium loosely fluffy and slightly cottony, white on top but below coloured with following shades: 1 A 2 to 1 C 2 (Peach blossom) to 2 I 2 (Rose Marie) to 3 J 3 (Mayflower) to 5 E 3 (Nectar).	Unchanged. Coloured as follows: 1 A 2 to 1 C 2 (Peach blossom) to 2 I 2 (Rose Marie) to 3 J 3 (Mayflower) to 5 E 3 (Nectar); 4 I 8 (Colonial rose), 4 K 9 (Doge).
S 20A	Aerial mycelium present, not cottony, but somewhat short and woolly on the rice grains. On top pale white but coloured below with: 1 B 2, 1 C 2 (Peach blossom), 42 D 1 (Dawn), 43 E 3, 44 F 4 (Vestal).	Mycelium fluffy, not cottony, forming a dense mat of short hyphae pale white to pink. Intensity of shades: 1 B 7 (Pink 1 T), 1 C 7 (Pink 2 T). 1 D 7 (Rose Breath) to 1 G 7 (Debutante Pk. La France Pk.); 42 B 1 (Zephyr) to 42 B 2.	Unchanged. Colours same as at the end of 21 days.

S 20B	Aerial mycelium present, somewhat cottony, white on top but coloured below as follows: 1 G 7 (La France Pk.), 2 F 7 (Blossom Venetian Pk.), 3 G 7 (Lilac), 3 J 3 (Mayflower), 4 J 3 (Azalea), 47 J 7.	Unchanged. Colours as follows: 2 D 2 to 2 I 2 (Rose Marie) to 3 I 2 (Vassar rose), 4 I 8 (Colonial rose) to 5 J 9 (Bois de Rose); 6 D 3 (Livid Br.).	Unchanged, but coloured as follows (with no shade of pink or red): 44 A 6 (Dutch Bl.) to 44 B 6 to 45 E 7 (Rainier Bl.) to 47 C 8.
S 20C	Aerial mycelium present, somewhat fluffy. Tinged with following: 1 D 1, 1 E 8 (Cupid Pk.), 2 I 8 (Jasper Pk.), 3 J 8 (Tango Pk.), 43 C 3 (Ageratum blue), 45 C 3.	Unchanged. Coloured as follows: 6 D 3 (Livid Br.) to 6 E 2, 4 G 1 (Livid V.), 3 G 1 (Corinthian Pk.), 3 E 7 (Powder Pk.), 3 E 8; also 43 C 3 (Ageratum blue); at bottom some development of 10 B 1 (Oyster white+).	Unchanged. Colours same as at the end of 21 days.
S 21	Aerial mycelium present, slightly fluffy, but not cottony. Tinged predominantly with: 43 C 3 (Ageratum blue), 45 A 3 (Platinum).	Unchanged. Coloured as follows: 41 B 2 to 42 D 4 to 43 C 3 (Ageratum blue) to 43 E 4 (Vanda) to 45 D 4. At bottom, 42 B 1 (Zephyr).	Unchanged. Colours same as at the end of 21 days.
Fusarium vasinfectum Atk. ..	Growth not fluffy or cottony. Colours produced were: 3 D 3, 6 I 5 (Raspberry), 6 G 6 (Ruby), 6 B 4 (Claret cup), 6 A 5 (Verninia Pr.), 7 C 5 (Sultana/Old Amethyst), 8 A 5.	Unchanged. Colours were: 3 D 1, 3 I 2 (Vassar rose), 3 G 1 (Corinthian Pk.), 3 A 7, 11 B 2 (Putty seed pearl cartridge buff) to 12 C 4 (Malacca). At bottom: 47 H 3 to 48 L 1 to 48 L 3 (Spanish Russian).	Unchanged. Following colours seen: 12 A 2 (Moonmist), 12 C 1 to 12 C 3 (Old Ivory), 45 G 5 (Crushed violets) to 45 H 6 (Old lilac) to 47 C 5 (Leadville) to 47 J 8 (Prune).
F. vasinfectum v. *lutulatum* ..	Growth not fluffy or cottony, but growth of short hyphae on the rice grains. Tinged with following colours: 1 A 8, 1 B 1, 1 B 7 (Pink 1 T), 1 B 8 (Opera Pink), 1 C 7 (Pink 2 T).	Unchanged. Coloured as follows: 1 B 7 (Pink 1 T) to 1 D 7 (Rose Breath) to 2 E 7 (Hydrangea Pk. Aurore).	Unchanged. Colours same as at the end of 21 days.

TABLE 2—*Continued*.

Fungus.	11 days.	21 days.	30 days.
F. vasinfectum f.1	Very slightly fluffy. Following colours developed: 1 B 2, 1 B 7 (Pink 1 T), 1 C 7 (Pink 2 T), 1 B 8 (Opera Pk.).	Straw-coloured fluffy with very little aerial mycelium and colours developed as follows: 1 B 7 (Pink 1 T), 1 B 8 (Opera Pk.), 1 C 7 (Pink 2 T), 1 D 7 (Rose Breath), 2 E 7 (Hydrangea Pk. Aurora).	Same as at the end of 21 days.
F. vasinfectum f.2	Details same as for *F. vasinfectum* f.1	Details same as for *F. vasinfectum* f.1	Details same as for *F. vasinfectum* f.1
F. vasinfectum v. *zonatum*	Growth fluffy but not cottony. Aerial mycelium on top pale white to grey, i.e., 13 B 1, 13 B 2 (Sand-Beach Chip+) to 13 D 2 (Bronze Clair). Also, 2 C 8, 2 A 8, 2 A 9, 3 A 9 (Sandust-Vanity), 3 E 7 (Powder Pk.), 48 J 7.	Flaky aerial mycelium on top. Tinged pink, i.e., 2 I 2 (Rose Marie+) 4 I 8 (Colonial Rose). Other shades noted were: 4 A 8, 4 B 8 (Tourelle) to 6 B 9 (Wood rose Sorghum Br.). At bottom: 11 C 2 (Ecru beige).	Aerial mycelium on top of a pale white to 46 D 6 (Plumbago-slate—colour. Below coloured as: 14 A 3 (Sandy beige Deytona—sand trift+) to 14 A 6 (Buckskin).
F. vasinfectum v. *zonatum* f.1	Growth not fluffy, aerial mycelium scanty. Tinged with following colours: 11 D 2 (Italian straw), 11 A 2 (Flesh natural Moon-light+), 11 A 4 (Nude Seasan—), 11 A 5 (Pastel Parchment Rose nude).	Pale white aerial mycelium on top only. Tinged below with following shades: 11 A 2 (Flesh. natural Moonlight—) to 11 B 3 (Champagne+ Bellock), 11 D 2 (Italian straw), 11 D 4 (Semitere) to 11 E 4 (Maple).	Same as at the end of 21 days.
F. vasinfectum v. *zonatum* f.2	Growth fluffy, cottony, white on top. Coloured below as follows: 2 E 7 (Hydrangea Pk.), 2 F 8, 2 G 8 (Rose leaf), 2 I 8 (Jasper Pk.), 2 K 8 (Begonia Gaiety), 3 J 8 (Tango Pk.), 51 A 2 (Opal Mauve), 45 D 3.	Aerial mycelium collapsed. Colours developed were: 2 F 7 (Blossom Venetian Pk.), 2 I 8 (Jasper Pk.), 2 K 8 (Begonia Gaiety), 2 J 9 (Springtime), 3 K 9 (Raspberry R).	Same as at the end of 21 days.

(3) Steamed rice was most suitable for formation of sclerotia. The only isolates which produced these were S 17 and S 20A and the culture of *F. vasinfectum* v. *zonatum* f.2.

(4) There was no constancy in the matter of production of aerial mycelium or a stroma. Growth of all isolates was somewhat cottony with white mycelium on sterilised pigeon pea stems. Aerial mycelium developed to some extent on potato dextrose agar, while on oatmeal agar development of aerial mycelium was poor or none at all.

(5) Development of stroma was good particularly on steamed rice. Stromatic colour consisted of pink to violet shades in all isolates and cultures except *F. vasinfectum* v. *zonatum* f.1. In the case of the latter stroma was straw or cream coloured.

Study of spore shape, size, etc. was confined to the author's isolates since it was considered superfluous to gather such data relating to the identified cultures in view of the illustrated descriptions of these already available (Wollenweber and Reinking, 1935), and more especially in so far as no significant differences in spore size between *F. vasinfectum*, its varieties and forms is evident from the descriptions

TABLE 3.

Showing colour reactions of Fusarium vasinfectum, *its varieties and forms, and author's isolates to acid and alkali.*

Culture or isolate.	Reactions to	
	Acid.	Alkali.
Fusarium vasinfectum	Crushed berry 6 F 4	Quaker blue 40 E 5
F. vasinfectum v. *lutulatum* ..	Araby 4 G 10	Hathi grey 37 C 1
F. vasinfectum f.1	Araby 4 G 16	Hathi grey 37 C 1
F. vasinfectum f.2	Araby 4 G 10	Hathi grey 37 C 1
F. vasinfectum v. *zonatum* ..	Mauve rose 7 E 5	Quaker blue 40 E 5
F. vasinfectum v. *zonatum* f.1 ..	No change	No change
F. vasinfectum v. *zonatum* f.2 ..	Tango Pk. 5 J 8	Navy blue 40 E 11
S 7	Colonial rose 4 I 8	Navy 3 40 A 10
S 17	Holly berry 4 L 10	Navy blue 40 E 11
S 19	Holly berry 4 L 10	Midnight 40 A 8
S 20A	Colonial rose 4 I 8	Light wedgewood 37 A 7
S 20B	Livid V. 4 G 1	Ensign 40 J 12
S 20C	Clove Pk. 6 K 5	Glacier blue 39 H 7
S 21	Saraband 6 K 8	Quaker blue 40 E 5

of Wollenweber and Reinking. Data on spore size of the author's isolates are tabulated in Table 1. Spore shape in the case of the author's isolates is illustrated by camera lucida drawings in Text-fig. 1.

All isolates produced microconidia in abundance and these were borne in false heads. They were also found along with macroconidia in slimy masses which were invariably of a cream colour. Microconidia were mostly one-celled, ovoid to reniform. Macroconidia were typically thin-walled, dorsiventral, falcate, 1–3-septate, often constricted and abruptly curved at the apex, mostly pedicellate at base. Both terminal as well as intercalary chlamydospores were produced by all isolates and cultures and there was little difference in their shape or size.

Consideration of conidial shape and size indicate little differences between the isolates studied. Further, comparison would indicate striking similarity of the present isolates to *Fusarium vasinfectum* and its varieties and forms (see Wollenweber and Reinking, 1935).

Colour Production: For studying colour production by the various isolates and cultures, steamed rice in test tubes was used. The inoculated cultures were incubated at 30°C. and records of colour, etc. were made at the end of 10, 21 and 30 days. The colour data are presented in detail (Table 2) since it is considered that they are important. It will be seen that all isolates and cultures except *F. vasinfectum* v. *zonatum* f.1 developed pink colours; the culture of *F. vasinfectum* v. *zonatum* f.1, however, developed pale dull colour, e.g., straw colour.

Colour reactions to acid and alkali: Reactions of cultures and isolates to acid and alkali were ascertained by addition of acid (dilute hydrochloric acid added in drops in sufficient quantity) or alkali (2% KOH solution similarly added in drops) to 30 days' old cultures on steamed rice. The results are presented in Table 3. It was found that the colour reactions to acid as well as alkali were very similar in the case of all isolates and cultures except that of *F. vasinfectum* v. *zonatum* f.1 which was not affected by addition of either acid or alkali. In the case of all other isolates and cultures, colour on addition of acid was some shade of pink or red, and that on addition of alkali was some shade of blue. There were, however, minor variations in the intensity of the pink and red or blue shades between these isolates and cultures.

TABLE 4.

Showing rate of growth (diameter in mm. of colony) of Fusarium vasinfectum, *its varieties and forms, and author's isolates on potato dextrose agar at room temperature (30°C.).*

Culture or isolate.	Days.							
	2	3	4	5	6	7	8	9
Fusarium vasinfectum	26	41	55	71	85	..	..	..
F. vasinfectum v. *latulatum*	23	34	43	56	67	78	90	..
F. vasinfectum f.1	19	25	31	38	43	50	56	61
F. vasinfectum f.2	26	42	57	75	89	..	..	..
F. vasinfectum v. *zonatum*	22	38	51	67	78	95	..	..
F. vasinfectum v. *zonatum* f.1	23	37	50	66	79	..	..	..
F. vasinfectum v. *zonatum* f.2	26	41	58	75	88	..	..	..
S 7	13	21	28	41	50	59	65	71
S 17	19	27	34	44	56	63	72	82
S 19	20	28	37	49	59	71	78	87
S 20A	21	33	42	53	63	74	84	..
S 20B	20	29	41	52	65	78	86	..
S 20C	21	31	45	57	68	82	93	..
S 21	16	22	29	32	52	62	70	79

Growth rate in culture.

Data on rate of growth of the various isolates and cultures on potato dextrose agar are presented in Table 4. From the data it appeared that there were differences in growth rate between the author's isolates though they were all similar morphologically.

Pathogenicity tests.

The results of pathogenicity tests on cotton plants using the various isolates and cultures are given in Table 5. There were differences between the isolates or

TABLE 5.

Showing results of pathogenicity tests with Fusarium vasinfectum, *its varieties and forms, and author's isolates on wilt-susceptible K2 cotton.*

Culture or isolate.	No. of seeds germinated.+	No. of plants wilted.	Wilt per cent.
Fusarium vasinfectum	117	3*	2·5*
F. vasinfectum v. *lutulatum*	121	28	23·1
F. vasinfectum f.1	129	83	64·3
F. vasinfectum f.2	126	11	8·7
F. vasinfectum v. *zonatum*	121	43	35·5
F. vasinfectum v. *zonatum* f.1 .. .	120	5*	4·1*
F. vasinfectum v. *zonatum* f.2 .. .	129	22	17·0
S 7	119	6	5·0
S 17	124	44	35·4
S 19	120	80	66·6
S 20A	115	89	77·3
S 20B	128	82	64·1
S 20C	120	32	26·6
S 21	127	81	63·7
Control	136	0	0

+ Total number of seeds sown in each case was 150.

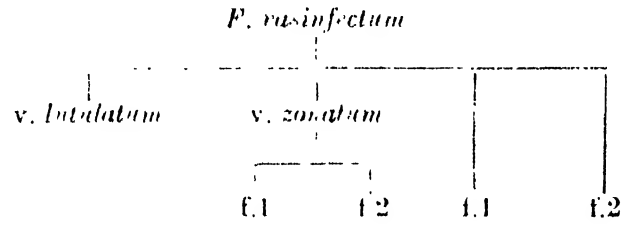
* Fungus isolated from wilted plants was different from the one used for inoculation in each case. Only *Fusarium solani* could be recovered from these diseased plants.

cultures in the matter of pathogenicity. Although much significance should not be attached to results obtained in pot experiments, it is nevertheless obvious that some isolates and cultures exhibited a high degree of pathogenicity, e.g. isolates S 19, S 20A, S 20B and S 21 and the culture of *F. vasinfectum* f.1. Cultures of *F. vasinfectum* and *F. vasinfectum* v. *zonatum* f.1 appeared to be very weakly pathogenic but this fact was not confirmed by the isolations obtained from infected plants from which only *Fusarium solani* could be recovered on plating. Amongst the cultures received from Holland, *F. vasinfectum* f.1 was most pathogenic, *F. vasinfectum* and *F. vasinfectum* v. *zonatum* f.1 not pathogenic at all. It is also obvious from the results that the author's isolates which were all morphologically similar exhibited different degrees of pathogenicity under the conditions of the experiment.

DISCUSSION.

Although the present investigation was primarily aimed at settling the specific identity of certain Fusaria isolated by the author from wilted cotton plants and 'wilt-sick' cotton soil, the inclusion, in this study, of cultures of *Fusarium vasinfectum*, its varieties and forms obtained from the Centraalbureau voor Schimmelcultures, Baarn, has yielded results which have a bearing on the taxonomy of this group of fungi.

The species *Fusarium rasinfectum* is treated in some detail by Wollenweber and Reinking (1935) in their 'Die Fusarien'. The species was first described by Atkinson (1892), but his description is meagre and itself does not enable us to recognise the species. Wollenweber and Reinking (1935) recognise two varieties, *lutulatum* and *zonatum*, two forms, viz., f.1 and f.2, and two forms (f.1 and f.2) for the variety *zonatum*. The forms are treated as entities independent of the varieties or species itself and similarly the varieties are treated as entities independent of the species. A perusal of the arrangement of species, varieties and forms in the Key on page 108 of 'Die Fusarien' would make this clear. It is unfortunate that this method has been followed since it is reasonable to consider *variety* to be of immediately lower rank to species and *form* to be of immediately lower rank to variety. A recognition of this fact would indicate the arrangement in the Key somewhat as follows:



Indeed, much of the difficulty experienced by those who try to identify Fusaria using Wollenweber and Reinking's Key could have been minimised by adopting some such arrangement, although even this arrangement is not satisfactory. It may be mentioned here that amongst the various amendments to the International Rules considered at the Seventh International Botanical Congress recently, the one relating to Article 28 is relevant to the present discussion. This amendment reads as: Insert before first paragraph: 'For nomenclatural purposes, a species and any taxon below the rank of a species is regarded as the sum of the lower taxa, if any. The description of a subordinated taxon which does not include the type of the higher taxon automatically creates a second subordinated taxon which includes the type of the higher taxon.' This amendment, if finally accepted, would certainly put taxonomy on a much better basis than at present, and is of immediate importance in *Fusarium* taxonomy and nomenclature.

It has to be stated, however, that the authors of 'Die Fusarien' were probably constrained to draw up the Key as they have done since in any attempt to follow the arrangement suggested above the distinction between some at least of the different varieties and forms recognised by them is likely to break down.

Apart from the data emerging from the present investigation, close study of the descriptions given by Wollenweber and Reinking (1935) indicate the following:

From the morphological standpoint, *Fusarium rasinfectum*, its varieties and forms have conidia very similar in shape and size. Spore measurements (see Wollenweber and Reinking, 1935, p. 124–26) are similar though 3-septate conidia of *F. rasinfectum* v. *zonatum* and its two forms are slightly longer than the other members of the present group. From the taxonomic standpoint these differences are of little significance though it is not so considered by Wollenweber and Reinking (1935). Range in spore size within the species *F. rasinfectum* is very wide and hence the author feels that slight variations in spore size alone should not be the basis for distinguishing varieties and forms within the species itself. In fact, Wollenweber and Reinking (1935) have stressed on other criteria in this matter. The key characteristics of the various varieties and forms of *F. rasinfectum* as set forth by Wollenweber and Reinking (1935) are as follows:

F. rasinfectum f.1 (Wollenweber, 1931, p. 423) is considered by them to be very similar to *F. rasinfectum* in all respects except that cultures of the former

lack smell. Indeed, the form had been originally given varietal rank by Wollenweber (1913) and, as v. *inodoratum*, was distinguished from *F. vasinfectum* only on the basis of lack of smell in the case of cultures of the former.

F. vasinfectum f.2 (Wollenweber and Reinking, 1935, p. 125) is considered to differ from *F. vasinfectum* solely on account of its doubtful pathogenicity and wilt production on cotton and it is stated that a number of representative isolates from the evacuation of bowels of children suffering from dyspepsia are included in this form.

F. vasinfectum v. *lutulatum* (Wollenweber, 1931, p. 424) is considered to differ from *F. vasinfectum* in possessing somewhat longer conidia and by the occasional appearance of abundant small (0·5 mm. diameter) dark blue sclerotial bodies.

F. vasinfectum v. *zonatum* (Wollenweber, 1931, p. 424) is distinguished from the above variety and forms by the growth of its mycelium in concentric zones, by the absence of dark blue sclerotial stromata, by the pale, nearly yellow colour of its sporodochial and conidial slime and by the few longer and thicker conidia.

F. vasinfectum v. *zonatum* f.1 (Wollenweber, 1931, p. 425) is said to differ from *F. vasinfectum* v. *zonatum* by the pale, cream coloured to lac-ochre-brown, seldom nearly purple, red stromata and occasional presence of vesicular swollen yellow-brown plectenchymatous knots of 0·5 mm. thickness in cultures of rice.

F. vasinfectum v. *zonatum* f.2 (Wollenweber, 1931, p. 425) is considered to differ from *F. vasinfectum* v. *zonatum* and its form 1 in that the first lacks aromatic smell and sclerotia, and has strongly purple coloured stromata, lilac coloured aerial mycelium and richly occurring pionnotes.

It will be obvious from the above summary that in the separation of varieties and forms of *F. vasinfectum*, Wollenweber and Reinking (1935) have used, besides spore size, the following criteria: (1) presence or absence of odour; (2) ability to produce wilt in cotton; (3) presence or absence of dark blue sclerotial bodies; (4) presence or absence of zonation in cultures; and (5) colour of stroma when present. In any classification of the fungi under study, the value of these criteria has to be properly assessed.

(1) Presence or absence of odour has been found to be an unreliable character and is of little help in distinguishing between *F. vasinfectum* and its form 1. Cultures of *F. vasinfectum* and its varieties and forms obtained from the Centraal-bureau voor Schimmelcultures did not show any recognisable differences in the production of aromatic odour. This observation confirms that of Kulkarni (1934).

(2) The inability to produce wilt in cotton is one of the criteria suggested for distinguishing between *F. vasinfectum* f.1 and *F. vasinfectum* f.2; the former is considered definitely pathogenic to cotton whereas the ability of the latter to cause wilt in cotton is stated to be uncertain. The pathogenicity tests reported here indicated that both forms 1 and 2 were pathogenic to wilt-susceptible Indian cotton, though the latter was only weakly pathogenic. Higher pathogenicity figures obtained for form 1 are doubtless in keeping with Wollenweber and Reinking's (1935) observations, and the low figures of mortality obtained by inoculation with form 2 appear to confirm the doubtful pathogenicity of this form on cotton suggested by Wollenweber and Reinking (1935). However, *F. vasinfectum* itself was not pathogenic to cotton in the tests carried out by the author. This again is probably in conformity with observations of Wollenweber and Reinking that *F. vasinfectum* causes cotton wilt in N. America, but its form 1 causes cotton wilt in N. America, in Egypt and in India. The culture of *F. vasinfectum* f.1 used in the present investigation is an Egyptian isolate originally obtained from Fahmy who demonstrated its ability to cause wilt in both American and Indian cottons (Fahmy, 1927). Yet, it would appear that we are dealing here with the question of physiologic specialisation, evidence of which in *F. vasinfectum* has been suggested by Mundkur (1936). In any case, much weight need not be attached to pathogenicity of these fungi in classifying them, particularly in view of the observations of Mundkur (1936) on the rôle of environment in the pathogenicity of

parasitic fungi and the resistance which host plants can offer to them. Mundkur showed that Indo-American and American cottons were immune to an American strain of *F. vasinfectum* when growing in Indian soils; similarly, Indo-American cottons growing on American cotton soils proved to be as susceptible as the American cottons to the American strain of the fungus, but were still immune to the Indian fungus. The writer's isolates, which were between themselves morphologically indistinguishable, moreover, exhibited a wide range of pathogenicity. It should also be noted that besides *F. vasinfectum* f.1 and *F. vasinfectum* f.2, other varieties and forms also exhibited pathogenicity on cotton.

(3) The only cultures which produced sclerotia were S 17, S 20A and *F. vasinfectum* v. *zonatum* f.2. No sclerotia were observed in cultures of *F. vasinfectum*, *F. vasinfectum* forms 1 and 2, and *F. vasinfectum* v. *lutulatum*, all of which are considered to produce sclerotia by Wollenweber and Reinking. The author's results further failed to confirm the inability of *F. vasinfectum* v. *zonatum* f.2 to produce sclerotia. Sclerotial formation is obviously a variable character and it would appear that undue emphasis has been laid on this character in the classification of the *Fusarium vasinfectum* group of Fusaria.

(4) No zonation was observed in cultures of *F. vasinfectum* v. *zonatum* and its forms 1 and 2 or in any of the other cultures and isolates studied. The usefulness of this phenomenon, therefore, in distinguishing between these fungi, is doubtful.

(5) Stromatic colour of all isolates and cultures except *F. vasinfectum* v. *zonatum* f.1 was pink to purple; stromatic colour in the case of *F. vasinfectum* v. *zonatum* f.1 alone was cream to ochre. This observation is in agreement with that of Wollenweber and Reinking (1935). Further, neither acid nor alkali could modify stromatic colour of this culture on rice. Indeed, the culture retains in a remarkable manner the stromatic colour originally claimed for it (Link and Bailey, 1926).

The above observations incline the author to consider the following varieties and forms synonyms of *Fusarium vasinfectum* Atk.: *F. vasinfectum* Atk. f.1 Wr., *F. vasinfectum* Atk. f.2 Wr. et Rg., *F. vasinfectum* Atk. v. *lutulatum* (Sherb.) Wr., *F. vasinfectum* Atk. v. *zonatum* (Sherb.) Wr., *F. vasinfectum* Atk. v. *zonatum* (Sherb.) f.2 (Lk. et Bail.) Wr. The distinct stromatic colour exhibited by *F. vasinfectum* Atk. v. *zonatum* (Sherb.) f.1 (Lk. et Bail.) Wr., coupled with its indifference to addition of acid or alkali indicates the need for re-considering its systematic position which is left an open question for the present. It would appear from the present instance that the production of red or blue colour with acid or alkali respectively is not universal within the section *Elegans*. On the basis of the results obtained, the author's isolates are also identified as *F. vasinfectum* Atk. although these isolates exhibited variation in regard to growth rate and pathogenicity on cotton.

Summary.

The results are presented of a study of certain Fusaria isolated from wilted cotton plants and 'wilt-sick' cotton soil from Southern India. All isolates studied belonged to the section *Elegans* and were similar morphologically but exhibited variation in regard to growth rate in culture and pathogenicity on cotton. The isolates were compared in detail with cultures of *Fusarium vasinfectum* Atk. and its varieties and forms obtained from the Centraalbureau voor Schimmelcultures, Baarn, Holland. On the basis of the data obtained, which are presented and discussed in detail, all varieties and forms of *F. vasinfectum* Atk. recognised by Wollenweber and Reinking (1935) with the exception of *F. vasinfectum* Atk. v. *zonatum* (Sherb.) f.1 (Lk. et Bail.) Wr. are considered synonyms of *F. vasinfectum* Atk. The Indian isolates are identified as *F. vasinfectum* Atk.

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ON THE MINIMAX APPROACH TO THE PROBLEM OF ESTIMATION.

By D. Basu, *Research Fellow, N.I.S.I., Statistical Laboratory, Calcutta.*

(Communicated by Prof. S. N. Bose, F.N.I.)

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Introduction.

The purpose of this paper is to lay emphasis on a few aspects of Professor Wald's approach to the problems of Statistical Inference with particular reference to Estimation. It has been pointed out that a minimax estimator may not exist in many important cases unless we suitably modify our loss function or truncate the parameter space.

The problem of point estimation is as follows. The form of the distribution function $F(x|\theta)$ of a certain population being known we have to estimate the unknown population parameter θ by means of a random sample $\mathbf{x} = (x_1, x_2, \ldots . x_n)$ from the population. The problem is clearly a problem of decision functions. We have to define a single valued function $d(\mathbf{x})$ $d(x_1, x_2, \ldots . x_n)$ defined over the entire n-dimensional sample space M such that $d(\mathbf{x})$ takes values in the parameter space Ω. When we get a sample $\mathbf{x} = (x_1, \ldots . x_n)$ we estimate the unknown θ by $d(\mathbf{x})$.

Let $W(\theta, d)$ be the loss or weight function. It stands for the loss that we suffer if we estimate the true θ by d. In other words $W(\theta, d)$ stands for the different weights that the statistician wants to give to the different possible wrong decisions. It will not be unrealistic to assume that $W(\theta, d)$ is a monotonic non-decreasing function of $|\theta - d|$. As a matter of fact we shall generally work with the following two simple types of weight functions namely

$$W(\theta, d) = (\theta - d)^2 \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (1.1)$$

$$W(\theta, d) = \begin{cases} 0 \text{ if } |\theta - d| \leqq l \\ 1 \text{ if } |\theta - d| > l \end{cases} \quad .. \quad .. \quad .. \quad .. \quad .. \quad (1.2)$$

The risk function or the expected loss function $r(\theta/d)$ corresponding to a particular decision function $d(\mathbf{x})$ is defined as follows:

$$r(\theta/d) = \int_M W(\theta, d(\mathbf{x}))\, dF(\mathbf{x}/\theta) \quad .. \quad .. \quad .. \quad (1.3)$$

where $$F(\mathbf{x}|\theta) = F(x_1|\theta) \ldots . F(x_n|\theta)$$

and M is the n-dimensional sample space. It will be noted that $r(\theta/d)$ is a function of θ and the form of the decision function $d(\mathbf{x})$ but is independent of the sample point.

It is very natural to try to discover a decision function for which the associated risk function is small over the whole parameter space Ω. This immediately leads to the following definitions.

Definition 1.1: The decision function $d_0(\mathbf{x})$ is said to be uniformly more powerful than $d_1(\mathbf{x})$ if $r(\theta|d_0) \leqq r(\theta|d_1)$ for all θ with the sign of inequality holding for at least one θ.

It is almost obvious that there cannot exist a decision function $d_0(\mathbf{x})$ that is uniformly more powerful than all other decision functions. For if possible let $d_0(\mathbf{x})$ be uniformly the most powerful and let $d_1(\mathbf{x}) = \theta_1$. Then it is clear that $r(\theta_1|d_1) = 0$ (assuming that $W(\theta, d) = 0$ when $\theta = d$) and since $r(\theta_1|d_0) \leq r(\theta_1|d_1)$ it follows that $r(\theta|d_0) = 0$ when $\theta = \theta_1$. Since $d_0(\mathbf{x})$ is more powerful than any alternative $d_1(\mathbf{x})$ it follows that $r(\theta|d_0) = 0$, and this can be true only if $W(\theta_1, d)$ is of a trivial nature. The above consideration leads us to the very important definition of admissible decision functions.

Definition 1.2:—The decision function $d_0(\mathbf{x})$ is said to be admissible if there exists no other decision function that is uniformly more powerful than $d_0(\mathbf{x})$.

Obviously no decision function that is inadmissible can be accepted. The main problem that arises in the Waldian approach to the classical problem of estimation is to show that certain estimators commonly in use are admissible decision functions. The following theorem first obtained by Rao (1945) is of great importance in the above connection. The theorem was independently obtained by Blackwell (1947) and was extended to convex loss functions by Hodges and Lehmann (1950) and by Barankin (1950).

Theorem 1.1:—If $t = t(\mathbf{x})$ be a sufficient statistic for θ then the class of admissible estimators of θ is a sub-class of all functions of t provided $W(\theta, d) = (\theta - d)^2$.

The extension of Rao's theorem to the case where $W(\theta, d)$ for every θ is a convex (downwards) function of d is almost immediate. For from convexity of $W(\theta, d)$ it follows that

$$E\{W(\theta, d)|t\} \geq W(\theta, \psi) \text{ where } \psi = \psi(t) = E(d|t)$$

and hence

$$\begin{aligned} r(\theta|d) = E|W(\theta, d)| &= E_t[E\{W(\theta, d)|t\}] \\ &\geq E\, W(\theta, \psi) \\ &= r(\theta|\psi) \end{aligned}$$

Wald has shown that under certain conditions the class of all Bayes' solutions forms a complete class of decision functions and it will be seen that when a sufficient statistic exists every Bayes' solution is a function of the sufficient statistic. Wald's theorem however is proved under some restrictive conditions on the parameter space Ω and the weight function $W(\theta, d)$. We take up the problem in some greater details in the next section

2. Minimax Decision Rule.

If the population parameter θ be itself a random variable with $\mu(\theta)$ as the distribution function defined over the space Ω then it may be considered desirable to minimise the average risk function

$$\bar{r}(\mu|d) = \int_{\Omega} r(\theta|d)\, d\mu(\theta) \qquad \ldots \quad \ldots \quad \ldots \quad (2.1)$$

Definition 2.1:—A decision function that minimises the average risk function $\bar{r}(\mu|d)$ is called a Bayes' solution of the decision problem.

Definition 2.2:—A class of decision functions is said to be a complete class of decision functions if no decision function outside that class is admissible.

Definition 2.3:—A decision function $d_0(\mathbf{x})$ is said to be a minimax decision function if it is admissible and further if it minimises the maximum risk associated with any decision function. In other words d_0 is a minimax decision function if it is admissible and

$$\operatorname*{Sup}_{\theta} r(\theta|d_0) \leq \operatorname*{Sup}_{\theta} r(\theta|d) \qquad \ldots \quad \ldots \quad \ldots \quad (2.2)$$

where d is any other decision function. By sup (supremum) of $r(\theta/d)$ we mean the least upper bound of $r(\theta/d)$ in Ω.

The criterion of admissibility and the further criterion of minimax are the two new criteria set up by Wald. The following theorems proved by Wald are of fundamental importance.

Theorem 2.1:—The class of Bayes' solutions is a complete class of decision functions, i.e. no decision function that does not minimise the average risk with respect to some a priori distribution $\mu(\theta)$ is admissible.

Theorem 2.2:—There exists a minimax decision function.

Theorem 2.3:—The minimax decision function is a Bayes' solution with respect to a least favourable a priori distribution and it generates a risk function that is constant over the parameter space Ω expecting possibly in a set of probability measure zero (with reference to the least favourable a priori distribution).

The decision problem considered by Wald covers almost all the problems of Statistical Inference and it is to be expected that such general theorems can be proved only under a set of restrictive assumptions (vide Wald (1950), Chap. 3). We shall presently study the real nature of some of these assumptions. It should be noted that a Bayes' solution is nothing but a decision function that minimises some average risk function. No a priori arguments are really brought into the picture and the Bayes' solutions are studied because of their important properties.

3. Non-admissibility of uniform weight function over an infinite range:—Wald (1939) attempted to solve the problem of finding the minimax estimate of a location parameter. He demonstrated that under certain condition there exists a minimax estimate of the location parameter and that the maximum likelihood estimate under certain further conditions is the minimax estimate. It is then deduced that $\bar{x}$ is the minimax estimate of the Normal mean when the variance is known. The proofs of Theorems 5 and 6 in the above paper are however not valid because the multiple integrals considered in (30), (31) and (32) of that paper are all divergent and as such the proofs through the change of the order of integration in (30) and (31) is inadmissible. The Bayes' solution with respect to the uniform a priori distribution over the infinite range $-\infty < \theta < \infty$ was found to generate a constant risk function and so it was deduced that the particular Bayes' solution is the minimax estimate. But the a priori density function $d\theta(-\infty < \theta < \infty)$ is not a true probability distribution and may very well lead to a decision function that is not admissible. The average risk function $\bar{r}(\mu/d)$, where $d\mu(\theta) = d\theta(-\infty < \theta < \infty)$, will be infinite and the question of minimising $\bar{r}(\mu/d)$ with respect to d does not arise at all. Take for instance the following example where the problem is to make an estimate of the Poisson mean θ the loss function being $(\theta - d)^2$ the space Ω being $0 < \theta < \infty$.

Let $$X = x_1 + x_2 + \ldots + x_n.$$

Since X is a sufficient statistic for θ it follows from Rao's theorem that we need restrict ourselves only to functions of X. Since X is a Poisson variable with mean $n\theta$ we have

$$p(X|\theta) = e^{-n\theta}\frac{(n\theta)^X}{X!} \quad (X = 0, 1, 2, \ldots) \quad \ldots \quad \ldots \quad (3.1)$$

and

$$r(\theta|d) = \sum_0^\infty (\theta - d(X))^2 p(X/\theta) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3.2)$$

Now if $d\mu(\theta) = d\theta \quad (0 < \theta < \infty)$ we have

$$\bar{r}(\mu|d) = \int_0^\infty d\theta \sum_0^\infty (\theta - d(X))^2 e^{-n\theta}\frac{(n\theta)^X}{X!} \quad \ldots \quad \ldots \quad (3.3)$$

Proceeding in the same way as in Theorem 5 of Wald (1939) we may write (by formally integrating term by term)

$$r(\mu|d) = \sum_{0}^{\infty} \frac{1}{X!} \int_{0}^{\infty} (\theta - d)^2 e^{-n\theta} (n\theta)^X \, d\theta . \qquad (3.4)$$

Now it is easily seen that the integral

$$\int_{0}^{\infty} (\theta - d)^2 e^{-n\theta} (n\theta)^X \, d\theta \qquad (3.5)$$

is a minimum when

$$d = \frac{\int_{0}^{\infty} \theta e^{-n\theta} (n\theta)^X \, d\theta}{\int_{0}^{\infty} e^{-n\theta} (n\theta)^X \, d\theta} \qquad (3.6)$$

$$= \frac{1}{n} \cdot \frac{\Gamma(X+2)}{\Gamma(X+1)} = \frac{X}{n} + \frac{1}{n} .$$

The risk function generated by the above decision function is

$$r\left(\theta \,\middle|\, \frac{X}{n} + \frac{1}{n}\right) = E\left(\theta - \frac{X}{n} - \frac{1}{n}\right)^2 = \frac{\theta}{n} + \frac{1}{n^2} \qquad (3.7)$$

whereas the risk function generated by $\frac{X}{n}$ is

$$r\left(\theta \,\middle|\, \frac{X}{n}\right) = E\left(\theta - \frac{X}{n}\right)^2 = \frac{\theta}{n} \qquad (3.8)$$

Thus the decision function (3.6) is not admissible.

It is therefore clear that the type of argument employed in Theorem 5 of Wald (1939) is not valid. We should be very careful while dealing with a priori weight functions in space Ω that are not true probability distributions.

Suppose the problem is to find the minimax estimate of the normal mean the variance being known. If we take our loss function as $(\theta - d)^2$ then assumption 3.3 in Wald (1950) is violated as the loss (or weight) function is not bounded. This however is not a very serious difficulty. Even if the loss function is unbounded it can be shown that the minimax estimate will exist in many cases.

In estimation the real difficulty arises with assumption 3.4 where it is assumed that the space of terminal decisions D^t (since for the present we restrict ourselves to non-sequential decision functions only the space D^t is the whole decision space) is compact in the sense of a suitably defined metric in D^t space. Now if the parameter space Ω be $-\infty < \theta < \infty$ then the space of all possible decisions also is from $-\infty$ to ∞ and as such assumption 3.4 is violated. Of course we can make the decision space compact by taking the parameter space Ω as $a \leqq \theta \leqq b$ but in that case further difficulties arise. With this truncated decision space the theorems of Wald hold true but the resulting analysis becomes extremely difficult. For instance the decision function $\bar{x}$ ceases to be admissible, for clearly the decision function

$$d_0(\mathbf{x}) = \begin{cases} \bar{x} \text{ if } a \leq \bar{x} \leqq b \\ a \text{ if } \bar{x} < a \\ b \text{ if } \bar{x} > b \end{cases} \qquad (3.9)$$

is uniformly more powerful than $\bar{x}$. Wald (1950) has shown that $d_0(\mathbf{x})$ also is not admissible. Although a minimax decision function exists in theory it is not known what it is or how to find it out. Thus for the sake of simplicity at least we have to take Ω as $-\infty < \theta < \infty$, in which case $\bar{x}$ is the minimax estimator.

4. Non-existence of a minimax solution when the decision space is not compact. Consider a rectangular population with range $(0, \theta)$ the problem being to find a minimax estimator of θ on the basis of a random sample $\mathbf{x} = (x_1, \ldots, x_n)$ the parameter space Ω being $0 < \theta < \infty$ and the loss function being of the type (1.2). The risk function is

$$r(\theta/d) = \int_0^{\theta} \ldots \int_0^{\theta} W(\theta, d) \frac{1}{\theta^n} dx_1 \ldots dx_n.$$

Let $\xi = \max(x_1, \ldots, x_n)$. Then it is easily verified that the density function of ξ is $p(\xi|\theta)d\xi = \frac{1}{\theta^n} n\xi^{n-1} d\xi$ and hence it follows that the probability density of $(x_1, x_2, \ldots, x_n)$ on the surface S_ξ where ξ lies between ξ and $\xi + d\xi$ is simply

$$p(x_1, \ldots, x_n, \xi)\, dx_1 \ldots dx_n = \frac{1}{n\xi^{n-1}} d\xi\, dx_1 \ldots dx_n.$$

Thus

$$r(\theta/d) = \int_0^{\theta} \frac{n\xi^{n-1}}{\theta^n} d\xi \int_{S_\xi} W(\theta, d) \frac{dx_1 \ldots dx_n}{n\xi^{n-1} d\xi}. \qquad \ldots \quad \ldots \quad (4.1)$$

Consider the following a priori distribution for θ namely

$$g(\theta|\alpha)\, d\theta = \frac{1}{\Gamma(\alpha)} \theta^{\alpha-1} e^{-\theta} d\theta \quad (0 < \theta < \infty, \alpha > 0).$$

Then

$$\bar{r}(g(\theta|\alpha)/d) = \bar{r}(\alpha/d) = \int_0^{\infty} r(\theta|d)\, g(\theta|\alpha)\, d\theta$$

= the average risk function.

By an easy change of the order of integration we have

$$\bar{r}(\alpha/d) = \int_0^{\infty} n\xi^{n-1} d\xi \int_{S_\xi} \frac{dx_1 \ldots dx_n}{n\xi^{n-1} d\xi} \int_{\xi}^{\infty} \frac{W(\theta, d)}{\theta^n} g(\theta/\alpha)\, d\theta.$$

Thus in order to minimise $\bar{r}(\alpha/d)$ all that we have to do is to choose $d = d(x_1, \ldots, x_n)$ in such a way that for every $(x_1, x_2, \ldots, x_n)$ the integral

$$\int_{\xi}^{\infty} \frac{W(\theta, d)}{\theta^n} g(\theta/\alpha)\, d\theta \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4.2)$$

$$= \int_{\xi}^{\infty} W(\theta, d) \frac{1}{\Gamma(\alpha)} \theta^{\alpha-n-1} e^{-\theta} d\theta$$

is a minimum.

Now since $W(\theta, d) = 0$ when $d-l \leq \theta \leq d+l$ and $W(\theta, d) = 1$ elsewhere we should, clearly choose $d \geq \xi + l$ and should choose d in such a way that

$$\int_{d-l}^{d+l} \frac{1}{\Gamma(\alpha)} \theta^{\alpha-n-1} e^{-\theta} d\theta \text{ is maximum.} \quad \ldots \quad \ldots \quad \ldots \quad (4.3)$$

Let $\alpha > n+1$ and let $\phi(y)$ be defined as

$$\phi(y) = \int_{y-l}^{y+l} \theta^{\alpha-n-1} e^{-\theta} d\theta \qquad (l \leq y < \infty)$$

Then

$$\phi'(y) = (y+l)^{\alpha-n-1} e^{-(y+l)} - (y-l)^{\alpha-n-1} e^{-(y-l)}$$

It is easily verified that $\phi'(y)$ remains > 0 up to a stage and then changes sign and remains always < 0. That is $\phi(y)$ increases for some time and then goes on decreasing.

Let $y = f(\alpha)$ be the point where $\phi(y)$ is a maximum.

Thus in order to minimise (4.2) or to maximise (4.3) we should choose

$$d(\mathbf{x}) = d\alpha(\xi) = \begin{cases} f(\alpha) & \text{so long as} \quad \xi \leq f(\alpha) - l \\ \xi + l & \text{as soon as} \quad \xi > f(\alpha) - l \end{cases} \quad \ldots \quad \ldots \quad (4.4)$$

Thus corresponding to the a priori density function $g(\theta/\alpha)/\theta$ for θ the Bayes' solution is as defined in (4.4) where it is easily verifiable that $f(\alpha) = \alpha + 0(1)$ (by $0(1)$ we mean a function of α that remains bounded as $\alpha \to \infty$).

Now consider the risk function $r(\theta/d\alpha)$ generated by the decision function $d\alpha(\xi)$. Clearly so long as $\theta < f(\alpha) - l$, $d\alpha(\xi) = f(\alpha)$ for every ξ and hence from the definition of our loss function we have $r(\theta/d\alpha) = 1$ for every $\theta < f(\alpha) - l$. (Since we shall ultimately make $\alpha \to \infty$ therefore we can assume α to be so large that $f(\alpha) - l > 0$.). When $f(\alpha) - l \leq \theta \leq f(\alpha) + l$ then either $\xi \leq f(\alpha) - l$ or ξ lies between $f(\alpha) - l$ and θ and in both the cases $d\alpha(\xi)$ (which is either $f(\alpha)$ or $\xi + l$) must lie between $\theta - l$ and $\theta + l$ and as such $r(\theta/d\alpha) = 0$ in this case.

When $\theta > f(\alpha) + l$ then $W(\theta, d\alpha) = 0$ only when $\theta - 2l \leq \xi \leq \theta$ and hence in this case

$$r(\theta|d\alpha) = \int_0^{\theta-2l} \frac{n\xi^{n-1}}{\theta^n} d\xi = \left(1 - \frac{2l}{\theta}\right)^n.$$

Thus we have

$$r(\theta|d\alpha) = \begin{cases} 1 & \text{for} \quad 0 < \theta < f(\alpha) - l \\ 0 & \text{for} \quad f(\alpha) - l \leq \theta \leq f(\alpha) + l \\ \left(1 - \frac{2l}{\theta}\right)^n & \text{for} \quad f(\alpha) + l < \theta < \infty. \end{cases} \quad \ldots \quad \ldots \quad (4.5)$$

Hence the average risk function

$$\bar{r}(\alpha|d\alpha) = \int_0^\infty r(\theta/d\alpha)\, g(\theta/\alpha) d\theta \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4.6)$$

$$= \int_0^{f(\alpha)-l} g(\theta|\alpha) d\theta + \int_{f(\alpha)+l}^\infty \left(1 - \frac{2l}{\theta}\right)^n g(\theta|\alpha)\, d\theta.$$

We now show that $\bar{r}(\alpha|d_\alpha)\to 1$ as $\alpha\to\infty$. As noted before $f(\alpha)=\alpha+0(1)\to\infty$ as $\alpha\to\infty$ Hence for every $\epsilon>0$, no matter how small, we can find an A such that for every $\alpha>A$ the integral

$$\int_{f(\alpha)+l}^{\infty}\left(1-\frac{2l}{\theta}\right)^{n} g(\theta|\alpha)\,d\theta>(1-\epsilon)\int_{f(\alpha)+l}^{\infty} g(\theta|\alpha)\,d\theta>\int_{f(\alpha)+l}^{\infty} g(\theta|\alpha)\,d\theta-\epsilon.$$

$\therefore$ for every $\alpha>A$ we have

$$\bar{r}(\alpha|d_\alpha)>1-\int_{f(\alpha)-l}^{f(\alpha)+l} g(\theta|\alpha)\,d\theta-\epsilon.$$

It is easily verifiable that the maximum of $g(\theta|\alpha)$ is attained at $\theta=\alpha-1$ and that $g(\alpha-1|\alpha)\to 0$ as $\alpha\to\infty$

Hence
$$\int_{f(\alpha)-l}^{f(\alpha)+l} g(\theta|\alpha)\,d\theta\to 0 \text{ as } \alpha\to\infty.$$

Thus it is proved that $\bar{r}(\alpha|d_\alpha)\to 1$ as $\alpha\to\infty$. It at once follows that $\operatorname{Sup}_\theta r(\theta|d)=1$ for every decision function $d(\mathbf{x})$. For if for a particular $d(\mathbf{x})$, $\operatorname{Sup}_\theta r(\theta|d)=1-\delta$ then for that d the average risk function

$$\bar{r}(\alpha|d)=\int_0^\infty r(\theta|d)\,g\,(\theta/\alpha)\,d\theta\leqq 1-\delta \text{ for all } \alpha.$$

But as $\bar{r}(\alpha|d_\alpha)\to 1$ there exists an α for which

$$\bar{r}(\alpha|d_\alpha)>\bar{r}(\alpha|d) \quad .. \quad .. \quad .. \quad .. \quad (4.7)$$

Which is a contradiction because d_α is the Bayes' solution corresponding to the a priori distribution $g(\theta|\alpha)$.

Thus we find that if the range of θ be from 0 to ∞ then for every decision function the maximum risk must be unity and hence the question of minimising the maximum risk does not arise. The reason why Wald's existence theorems do not hold in this case is that the decision space is not compact although all the other conditions are satisfied. It is conjectured that if θ be a location parameter then under certain very mild conditions (as for example $W(\theta, d)$ is a function of $|\theta-d|$ etc.) the minimax estimator for θ will exist even though the space Ω be unbounded. A general proof is yet to be given. It is also conjectured that in every case the minimax estimator will exist if we define our loss function suitably. As for example for the upper bound of the rectangular distribution the minimax estimator for θ will exist if we take our loss function $W(\theta, d)$ as say $(d-\log\theta)^2$.

5. Some comments on the estimation of Poisson mean when the parameter space is restricted:—The problem of estimating the parameters of a statistical distribution function when it is known, before the sample is drawn, that the parameter certainly belongs to a given set of numbers has been considered recently by Hammersley (1950) and it seems to present some points of peculiar interest. We now consider the problem of estimating the Poisson mean θ when it is a priori known that $0\leqq\theta\leqq 1$. The more general case of $0\leqq\theta\leqq a$ presents no new difficulties.

Let $\mathbf{x}=(x_1, x_2, \ldots, x_n)$ be a random sample drawn from a Poisson population with mean θ where it is known that $0\leqq\theta\leqq 1$ and let $X=x_1+\ldots+x_n$. Let $d(\mathbf{x})$ be an estimator of θ and let

$$r(\theta|d)=E(\theta-d(\mathbf{x}))^2$$

be the corresponding risk function.

Since the loss function is $(\theta-d)^2$ it follows from Rao's Theorem that we need consider only such estimators $d(\mathbf{x})$ as are functions of the sufficient statistics X. Again since X is a Poisson variable with mean $n\theta$ therefore there is no real loss of generality if we somewhat simplify our problem assuming that we are estimating on the basis of a single sample x. Thus if $d(x)$ be any estimator based on a single sample x then the corresponding risk function is

$$r(\theta|d) = \sum_{0}^{\infty} (\theta-d(x))^2 e^{-\theta} \frac{\theta^x}{x!} \quad (0 \leqq \theta \leqq 1) \qquad \ldots \qquad \ldots \qquad (5.1)$$

Now if $\xi(\theta)$ be any a priori distribution function over the parameter space $0 \leqq \theta \leqq 1$ then the corresponding average risk function is

$$\bar{r}(\xi|d) = \int_0^1 r(\theta|d)\, d\xi(\theta) \qquad \ldots \qquad \ldots \qquad \ldots \qquad (5.2)$$

$$= \sum_{0}^{\infty} \frac{1}{x!} \int_0^1 (\theta-d)^2 e^{-\theta} \theta^x d\xi(\theta)$$

The term by term integration in (5.2) is permissible as the series in (5.1) is uniformly convergent in $0 \leqq \theta \leqq 1$ for all estimators $d(x)$ that take values only in the range 0 to 1. Clearly we need not consider any estimator $d(x)$ that takes values outside the interval (0, 1) for corresponding to any such estimator we can always find another estimator always lying in (0, 1) but generating a risk function that is uniformly less than $r(\theta|d)$. Now $r(\xi|d)$ will be a minimum if corresponding to any x we choose $d(x)$ in such a way that the integral

$$\int_0^1 (\theta-d(x))^2 e^{-\theta} \theta^x d\xi(\theta) \text{ is a minimum.}$$

In other words the Bayes' solution corresponding to the a priori distribution $\xi(\theta)$ is

$$d_\xi(x) = \frac{\int_0^1 \theta^{x+1} e^{-\theta} d\xi(\theta)}{\int_0^1 \theta^x e^{-\theta} d\xi(\theta)} \qquad \ldots \qquad \ldots \qquad \ldots \qquad (5.3)$$

If we define the distribution function $\xi_1(\theta)$ as

$$\xi_1(\theta) = \frac{\int_0^\theta e^{-\eta} d\xi(\eta)}{\int_0^1 e^{-\eta} d\xi(\eta)} \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \qquad (5.4)$$

then it follows that

$$d_\xi(x) = \frac{\int_0^1 \theta^{x+1} d\xi_1(\theta)}{\int_0^1 \theta^x d\xi_1(\theta)} = \frac{\mu_{x+1}}{\mu_x} \qquad \ldots \qquad \ldots \qquad (5.5)$$

where μ_x is the x^{th} moment of θ with respect to the distribution $\xi_1(\theta)$. Wald has proved that under certain conditions (which are satisfied here) every Bayes' solution

is an admissible decision function and that the class of all Bayes' solutions is a complete class of decision functions. Thus we have the following:

Theorem 5.1:—A necessary and sufficient condition in order that an estimator $d(x)$ of the Poisson parameter θ $(0 \leqq \theta \leqq 1)$ be admissible is that

$$d(x) = \frac{\mu_{x+1}}{\mu_x}$$

where μ_x is the x^{th} moment of a random variable distributed over the interval $(0, 1)$.

That the condition is sufficient is proved as follows:

If
$$d(x) = \frac{\mu_{x+1}}{\mu_x} = \frac{\int_0^1 \theta^{x+1}\, d\xi_1(\theta)}{\int_0^1 \theta^x\, d\xi_1(\theta)}$$

then defining

$$\xi(\theta) = \int_0^\theta e^\eta\, d\xi_1(\eta) \Big/ \int_0^1 e^\eta\, d\xi_1(\eta)$$

we have

$$d(x) = \int_0^1 \theta^{x+1} e^{-\theta}\, d\xi(\theta) \Big/ \int_0^1 \theta^x e^{-\theta}\, d\xi(\theta) = d_\xi(x)$$

i.e. $d(x)$ is the Bayes' solution corresponding to the a priori distribution $\xi(\theta)$ and as such is admissible. Now since the quadratic form in u, v, namely

$$\int_0^1 \left(u\theta^{\frac{x-1}{2}} + v\theta^{\frac{x+1}{2}}\right)^2 d\xi_1(\theta)$$

$$= u^2 \mu_{x-1} + 2uv\, \mu_x + v^2 \mu_{x+1}$$

is positive definite therefore it follows that

$$\mu_{x-1}\, \mu_{x+1} \geqq \mu_x^2$$

or
$$d_\xi(x) = \mu_{x+1} \,|\, \mu_x \geqq \mu_x \,|\, \mu_{x-1} = d_\xi(x-1).$$

If the sign of equality holds for any x then it follows that there exists two constants u_0 and v_0 such that

$$u_0\theta^{\frac{x-1}{2}} + v_0\theta^{\frac{x+1}{2}} = 0$$

for all θ excepting possibly in a set of probability measure zero under the d.f. $\xi_1(\theta)$.

But the above equation is satisfied only when

$$\theta = 0 \quad \text{or} \quad \theta = -\frac{u_0}{v_0}$$

Thus we have proved the following:

Theorem 5.2:—The Bayes' solution $d_\xi(x)$ is a strictly increasing function of x excepting when the d.f. $\xi(\theta)$ is such that θ can take only one or two values (one of which is zero) under $\xi(\theta)$.

If under $\xi(\theta)$ θ takes the value α $(0 \leqq \alpha \leqq 1)$ with unit probability then the corresponding Bayes' solution is obviously $d_\xi(x) = \alpha$ for all x.

If under $\xi(\theta)$ θ takes only the two values 0 and α $(0 < \alpha \leqq 1)$ then the corresponding Bayes' solution is

$$d_\xi(x) = \begin{cases} C & \text{when } x = 0 \\ \alpha & \text{when } x > 0 \end{cases} \quad (0 < C < \alpha \leqq 1)$$

If $d\xi(\theta) = \text{Const.}\, e^{\theta}\theta^{l-1}(1-\theta)^{m-1}d\theta$ $(0 \leqq \theta \leqq 1, l > 0, m > 0)$ then it is easily verified that

$$d_\xi(x) = \frac{x+l}{x+l+m}$$

Thus corresponding to every a priori distribution function $\xi(\theta)$ there exists a unique Bayes' solution $d(\xi(x)$ that minimises the average risk $r(\xi/d)$ the minimum value being denoted by r_ξ $r(\xi/d_\xi)$

Wald has shown that there exists a d.f. $\eta(\theta)$ called the least favourable a priori d.f., such that $r_\eta \geq r_\xi$ for any alternative d.f. $\xi(\theta)$.

Further the minimax decision function is the Bayes' solution corresponding to the least favourable a priori d.f $\eta(\theta)$ and the risk function generated by $d_\eta(x)$ is $= r_\eta$ for all θ $(0 \leqq \theta \leqq 1)$ It at once follows that $r(\theta/d_\eta)$ r_η for all θ excepting possibly in a set if probability measure zero under the d.f. $\eta(\theta)$.

Now since the series in (5.1) is uniformly convergent in $0 \leqq \theta \leqq 1$ for all admissible decision function $d(x)$ we have that $r(\theta/d_\eta)$ is a continuous function of θ. Hence if $\eta(\theta)$ be a continuous distribution function then it follows that the risk function $r(\theta/d_\eta)$ generated by the minimax decision function $d_\eta(x)$ is a constant over the range $0 \leqq \theta \leqq 1$.

But if
$$r(\theta/d) = \sum_0^\infty (\theta - d(x))^2 e^{-\theta}\frac{\theta^x}{x!} = C$$

then by multiplying both sides by e^θ and equating for like powers of θ we have the difference equation

$$d^2(0) = C \quad .. \quad .. \quad .. \quad .. \quad (5.6)$$

$$d^2(n) - 2n\,d(n-1) + n(n-1) = C \text{ for } n > 0.$$

But since $d(n)$ lies in the range (0, 1), $d(x)$ being admissible, therefore the l.h.s. of (6) is of order n^2 whereas the r.h.s. is a constant. Thus we have the following:

Theorem 5.3. There exists no admissible decision function that generates a constant risk function.

In an appendix we give an interesting proof of the fact that the difference equation (6) cannot be solved even when there is no restriction on $d(x)$ and the r.h.s. is a function of n that does not increase too rapidly.

An immediate consequence of Theorem 5.3 is

Theorem 5.4 :—The least favourable a priori d.f. $\eta(\theta)$ is discrete.

Let ξ^π be the simple discrete distribution of θ under which θ takes the values 0 and 1 with probabilities $(1-\pi)/1 + (e-1)\pi$ and $e\pi/1+(e-1)\pi$ where $0 < \pi < 1$. From (5.4) we have the associated d.f. ξ_1^π as one under which θ takes the values 0 and 1 with probabilities $1-\pi$ and π respectively.

From (5.5) we have the corresponding Bayes' solution

$$d^\pi = d_{\xi^\pi}(x) = \begin{cases} \pi \text{ when } x = 0 \\ 1 \text{ when } x > 0 \end{cases} \quad .. \quad .. \quad .. \quad (5.7)$$

The risk function generated by $d^{\pi}(x)$ is

$$r(\theta|d^{\pi}) = (\theta-\pi)^2 e^{-\theta} + (\theta-1)^2(1-e^{-\theta}) \quad \ldots \quad (5.8)$$

and the corresponding average risk is

$$\bar{r}_{\pi} = \bar{r}(\xi^{\pi}|d^{\pi}) = \int_0^1 r(\theta/d^{\pi})\, d\xi^{\pi}(\theta) \quad \ldots \quad (5.9)$$

$$= \frac{\pi(1-\pi)}{1+(e-1)\pi}$$

It can be easily verified that $\bar{r}_{\pi}$ is a maximum when

$$\pi = (1+\sqrt{e})^{-1} = \pi_0 \text{ (say)}$$

Thus in the class of all a priori distributions of the form $\xi^{\pi}(0 \leqq \pi \leqq 1)$ the least favourable d.f. is the one for which $\pi = \pi_0$. We shall see afterwards that this is not the least favourable d.f. in the whole class. Now it is easily verified that

$$r(0/d^{\pi_0}) = r(1/d^{\pi_0}) = \bar{r}_{\pi_0} = (1+\sqrt{e})^{-2} \quad \ldots \quad (5.10)$$

Again since d^{π_0} is the Bayes' solution corresponding to the a priori d.f. ξ^{π_0} under which θ can take only the two values 0 and 1, therefore we have the following.

Theorem 5.5.:—For every $d(x)$ $\sup_{\theta} r(\theta/d) > (1+\sqrt{e})^{-2}$.

For if there exists a $d(x)$ other than $d^{\pi_0}(x)$ for which $r(\theta/d) \leqq (1+\sqrt{e})^{-2}$ for both $\theta = 0$ and 1 then that will contradict the fact that $d^{\pi_0}(x)$ is the unique Bayes' solution corresponding to ξ^{π_0}. Again it is easily verified that $\frac{d}{d\theta} r(\theta|d^{\pi}) > 0$ at $\theta = 0$ so long as $\pi < (1+\sqrt{2})^{-1}$ and since $\pi_0 < (1+\sqrt{2})^{-1}$ we have that $r(\theta|d^{\pi_0})$ is an increasing function at $\theta = 0$ which proves the theorem.

Since $r(\theta|d^{\pi_0})$ is an increasing function at $\theta = 0$ it follows that $r(\theta|d^{\pi_0}) > \bar{r}_{\pi_0}$ for some θ and so ξ^{π_0} is not the least favourable a priori d.f. When $\pi = (1+\sqrt{2})^{-1}$ it is easily seen that $\sup r(\theta|d^{\pi})$ is attained at $\theta = 0$ and $\sup r(\theta|d^{\pi}) = (1+\sqrt{2})^{-2}$ Thus we have finally:

Theorem 5.6. $$(1+\sqrt{e})^{-2} < \inf_{d} \sup_{\theta} r(\theta|d) < (1+\sqrt{2})^{-2}.$$

Appendix:—

Here we prove that the difference equation (a particular case of which we considered in (5.6))

$$u_0^2 = K(0)$$

$$u_m^2 - 2m\,u_{m-1} + m(m-1) = K(m) \text{ for } m > 0$$

has no real solution if

$$\overline{\lim}\, \frac{K(m)}{m} < 1$$

$$\left(\text{If } K(m) \text{ is a constant then } \overline{\lim}\, \frac{K(m)}{m} = 0\right).$$

Proof:—From $$u_m^2 - 2m\,u_{m-1} + m(m-1) = K(m)$$

$$2m\,u_{m-1} \geqq m(m-1) - K(m)$$

or

$$\frac{u_{m-1}}{m-1} \geq \frac{1}{2} - \frac{K(m)}{2m(m-1)}$$

$$\therefore \varliminf \frac{u_{m-1}}{m-1} \geq \frac{1}{2} - \varlimsup \frac{K(m)}{2m(m-1)}$$

Since by supposition $$\varlimsup \frac{K(m)}{m} < 1$$

$$\therefore \varlimsup \frac{K(m)}{2m(m-1)} \leq 0 \text{ and therefore we have}$$

$$\varliminf \frac{u_m}{m} \geq \frac{1}{2}. \qquad \ldots \ldots \ldots \ldots \ldots \ldots \text{(a.1)}$$

Now if $$\varliminf \frac{u_m}{m} \geq \alpha_0$$

then $$u_m > (\alpha - \delta)\, m \text{ for all } m \geq N \quad N(\delta)$$

and then $$2m\, u_{m-1} = u_m^2 + m(m-1) - K(m)$$

$$> (\alpha_0 - \delta)^2 m^2 + m(m-1) - K(m)$$

$$\therefore \frac{u_{m-1}}{m-1} > (\alpha_0 - \delta)^2 \frac{m^2}{2m(m-1)} + \frac{1}{2} - \frac{K(m)}{2m(m-1)} \text{ for all } m \geq N.$$

$\therefore \varliminf \frac{u_{m-1}}{m-1} \geq \frac{1}{2}\{1 + (\alpha_0 - \delta)^2\}$ and since δ is arbitrary we have the following result

$$\varliminf \frac{u_m}{m} \geq \alpha_0 \text{ implies that } \varliminf \frac{u_m}{m} \geq \tfrac{1}{2}(1 + \alpha_0^2). \qquad \ldots \ldots \text{(a.2)}$$

Now let $\alpha_0 = \frac{1}{2}$ and $\alpha_n = \frac{1}{2}(1 + \alpha_{n-1}^2)$

It is easily seen that the sequence $\{\alpha_n\}$ is a monotonic increasing bounded sequence and as such $\lim \alpha_n = \alpha$ exists.

$$\because \alpha_n = \tfrac{1}{2}(1 + \alpha_{n-1}^2)$$

$\therefore$ making $n \to \infty$ we have $\alpha = \frac{1}{2}(1 + \alpha^2)$ and hence $\alpha = 1$.

But $\varliminf \frac{u_m}{m} \geq \alpha_n$ for every n and therefore $\ldots \ldots \ldots \text{(a.3)}$

$$\varliminf \frac{u_m}{m} \geq 1.$$

Again since the difference equation can be written in the form $(u_m - m)^2 + 2m(u_m - u_{m-1}) = m + K(m)$ we at once have

$$u_m - u_{m-1} \leq \frac{1}{2} + \frac{K(m)}{2m} \qquad \ldots \ldots$$

and since $$\varlimsup \frac{K(m)}{m} < 1$$

$$\therefore \varlimsup (u_m - u_{m-1}) < 1. \qquad \ldots \ldots \ldots \ldots \text{(a.4)}$$

Hence there exists a $\delta > 0$ and an N such that

$$u_{N+i} - u_{N+i-1} < 1 - \delta \quad \text{for } i = 1, 2, -\ldots \text{ ad inf.}$$

$$\therefore u_{N+n} - u_N = \sum_{1}^{n} (u_{N+i} - u_{N+i-1})$$

$$< (1-\delta)n$$

$$\therefore \frac{u_{n+N}}{N+n} < (1-\delta)\frac{n}{N+n} + \frac{u_N}{N+n}$$

and hence making $n \to \infty$ we have

$$\overline{\lim} \frac{u_m}{m} \leqq 1 - \delta \quad \text{which contradicts (a.3)} \ldots \quad \ldots \quad \ldots \quad \text{(a.5)}$$

Thus the required result is proved.

Summary.

It is shown that minimax estimators need not exist in many familiar cases unless the parameter space be truncated or the loss function suitably modified. For the rectangular distribution with range $(0, \theta)$ there do not exist any minimax estimator for θ if the loss function be of the simple zero-one type. The case of the Poisson mean has been considered in some details and a few interesting results obtained. The mean θ is assumed to be between 0 and 1 and the loss function is taken to be the square of the error. A complete characterization of the class of admissible estimators is given. It is proved that the least favourable a priori distribution must be discrete, for there exists no estimator that generates a constant risk function. Bounds for the minimum of the maximum risk have also been given.

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AN ALGAL FLORA FROM THE LAKI (LOWER EOCENE) BEDS OF THE NAMMAL GORGE (PUNJAB SALT RANGE)—I ARCHAEOLITHOTHAMNIUM

By C. P. VARMA, *M.Sc., Ph.D., F.B.S., Department of Geology, Lucknow University*

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INTRODUCTION.

The geology of the Nammal Gorge section (32° 40′ : 71° 48′) in the Salt Range, Punjab (Pakistan), was first made known by Wynne (1878). His palaeontological collections were later worked out by Waagen (1881) and Cowper Reed (1931, 1944). The Nammal Gorge section shows little structural complexities and includes an almost continuous record of the Tethys from the Permian Middle Productus limestones to the Lower Eocene Laki Beds. Gee (1946) has given the stratigraphy of the area which shows the following sequence, in which the beds I have noticed to be algal-bearing are marked with an asterisk.

Pleistocene conglomerates

——————— unconformity ———————

Lower Nimadrics (Miocene—Pliocene)

——— Time interval; Regional unconformity ———

* Sakesar limestones (Laki)	Eocene
Nammal limestones and shales	
Patala shales (Ranikot)	
* Khairabad limestones (Ranikot)	
Dhok Pass beds (Ranikot)	

———(Time interval; Regional unconformity)——

Baroch limestones	Jurassic[1]
Variegated stage	

————(Regional unconformity)————

Kingriali Dolomites	Trias (?)
Kingriali Sandstones	

————(Conformable, transitional junction)————

Ceratite beds	Trias
Upper Productus beds	Permian
* Middle Productus limestones	

(Base of the Middle Productus beds not exposed)

My studies are based on the specimens collected by Prof. S. R. N. Rao in 1946 from these beds at fairly short intervals. In the present paper I am confining myself to an account of the various species of the genus *Archaeolithothamnium* (Rhodophyceae) found in the Laki (Lower Eocene) beds of the Nammal Gorge.

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[1] An upper Cretaceous limestone at the upper part of the Baroch limestone with *Globotruncana* has been reported by Rao and Tripathi (1950) below the Ranikot (Palaeocene) beds.

The genus *Archaeolithothamnium* was first defined by Rothpletz in 1891 to include forms with isolated sporangia distributed all over the perithallium, there being no conceptacles to enclose them. Later, Lemoine (1917, p. 240; 1939, p. 37) gave a more comprehensive definition of the genus which included the following diagnostic characters: isolated sporangia, ovoid or pear-shaped, arranged in concentric zones; hypothallial cells arranged in loose files without continuous horizontal partitions as in the genus *Lithothamnium*. Each row is generally creeping or horizontal, becoming obliquely erect to merge gradually into the perithallium. In branched species of *Archaeolithothamnium* the medullary hypothallium shows a fan shaped to concentric arrangement of cells similar to that of *Lithothamnium* or *Lithophyllum* type. Mlle. Pfender (1926, p. 25) has called attention to the occurrence of secondary or recurrent basilar hypothallium in the regions of the older perithallium where the sporangia have decayed away. The presence of a recurrent hypothallium has been considered (Pia, 1936, p. 35) to be characteristic of the genus, although such a tissue has also been noticed in *Mesophyllum Savornini* Lem.

Archaeolithothamnium samanensis N. Rao has been described by him (1941, p. 44) to be 'unique in showing a tendency for concentric arrangement of the cells of the hypothallium and represents an intermediate type between *Archaeolithothamnium* and *Lithophyllum*'. It is interesting to note that Lemoine (1923, pp. 67–69) found in her species *Lithophyllum vignyense* (which she later 1928, p. 253, revised to *Mesophyllum vignyense*) an intermingling of the characters of *Lithothamnium* and *Lithophyllum*.

The genus shows an encrusting habit of the thallus which may be slightly nodulated or profusely lobed. Some lobes increase more in height and look like branches. Though the excessive increase in the length of a lobe is not considered to be a branch, the truly branched forms possessing a medullary hypothallium are well known from France, e.g. *A. turonicum* Rothpl., *A. amphiroaeforme* Rothpl. etc. (see Pfender, 1926, pp. 15–26) and India, e.g. *A. samanensis* N. Rao (1941, p. 45). *Archaeolithothamnium* species with zonated thalli are seldom met with (*A. digitatum* Pfender, *A. affine* Howe, *A. langrinensis* K. S. Rao, etc.). The zonation is caused either by the superimposition of a number of thalli of the same or different species, or it may be due to the intercalation of thin streaks of limestone or by the alternation of heights in the cell rows of the perithallium but true zonation characteristic of *Lithothamnium* and *Mesophyllum* is not known.

The type of conceptacles found in *Archaeolithothamnium* (isolated sporangia arranged in files), are known to occur in a recent genus *Sporolithon* possessing cruciate tetrasporangia (see Fritsch, 1945, p. 653). Fritsch (1945, pp. 653, 655) regards that 'the kind of sorus found in *Archaeolithothamnion* may well be primitive and have led to the more defined type seen in *Lithothamnion* and *Epilithon*, which in turn, may have resulted in the conceptacle with a single aperture. Such a view is justified by certain similarities in development'. Further, he states (1945, p. 655) that the characters of the sporangial conceptacles were more useful in tracing the affinities of the genera than the sexual characters. He suggests three lines of development in the family Corallinaceae: First exemplified by *Lithothamnion* and *Epilithon*; second by *Melobesia*, *Lithophyllum*, and *Choreonema*, and the third by *Amphiroa* and *Corallina*.

The genus first appears in the Lower Cretaceous and a few living species are known.

Previous records of the genus Archaeolithothamnium in India.

The earliest record of the genus in India (Andaman Islands) goes as far back as 1926 when Gee (1926) figured and described a species under the name *Lithothamnion nummuliticum*. The forms identified by Gee under *Lithothamnion nummuliticum* have been doubted by S. R. Narayana Rao (1941, p. 44) who states '*L. nummuli-*

ticum is now recognised to be *A. nummuliticum* and Mr. Gee's description and figures leave no doubt that his species is an *Archaeolithothamnium*".

The same year (1926, pp. 4-6) Das Gupta recorded two species of *Lithothamnium* (?) viz. *L. grandis* and *L. cherrapunjiensis* which have been recognised by K. S. Rao (1943, p. 286–287) to be the synonyms of *Corallina grandis* Rao and *Archaeolithothamnium cherrapunjiensis* Rao (p. 272) respectively. He has also recognised (1945) four new species of *Archaeolithothamnium* from the Tertiary rocks of Assam.

The genus is also known from the Upper Cretaceous of the Trichinopoly district, South India, where Pia (L. Rama Rao and J. Pia, 1936) records the presence of the following: *A. lugeoni* Pfender, *A. aff. provinciale* Pfender, *A.* c.f. *lycoperdioides* (Mich) Lem. and *A.* sp. indet.

Two new species of the genus *A. samanensis* and *A. ranikotensis* have been described from the Samana Range (Lower Eocene) Punjab, by S. R. Narayana Rao (1941).

Archaeolithothamnium zonatum sp. nov.

(Pl. XII, figs. 1 and 2.)

Diagnosis:

Thallus encrusting and slightly mammillated; perithallial lattice showing a compact mesh of cells with well-defined vertical and horizontal cell walls; zonation noticed. Cells rectangular to squarish. Hypothallium feebly represented. Sporangia big and ovoid.

Measurements:

Perithallial cells	..	.. 13–18·2 μ × 10·4 – 15·6 μ
Hypothallial cells	..	.. 13 15·6 μ × 10·4 13 μ
Sporangia	..	.. 117–148 μ × 58–78 μ
		mostly 130 μ × 65 μ

Description:

Thallus encrusting, slightly mammillated or lobed, branches not known. The perithallial lattice consists of squarish to mostly rectangular cells. The horizontal and vertical cell walls are well defined. Sometimes, squarish cells are observed below the sporangial rows. The thallus gives a distinctly zonated appearance. The hypothallium is feebly developed and consists typically of horizontal files which gradually bend into the perithallium. Most of the hypothallial cells measure 13 μ × 10·4 μ. The sporangia arranged in straight or slightly curved files. The species is characterised by a zonated perithallium, and sporangia which are the biggest among the so far known Indian species.

Comparison:

The three species of the genus comparable to it are: *A. lugeoni* Pfender, described from Trichinopoly district (Rao and Pia, 1936); *A. samanensis* Rao from the Samana Range, Punjab and *A. floridanum* Johnson and Ferris from Florida.

Though *A. lugeoni* shows some resemblance to the new species with regard to the dimensions of the perithallial cells it has, however, sporangia of smaller dimensions.

A. samanensis Rao, makes an approach in respect to the dimensions of the hypothallial cells but shows differences with regard to the perithallial cells and the shape and size of the sporangia which are 'ovoid rectangular in shape, the two vertical sides almost straight and parallel, the roof flat to slightly convex and the base tapering to a point' (Rao, 1941, p. 47). The sporangial measurements of this species as measured in the type slides are noted in the following table.

A. floridanum shows fairly big and ovoid sporangia but clearly differs in the perithallial and hypothallial (?) characters and the measurements of the vegetative cells and the sporangia.

Serial No.	Name.	Perithallial cells in μ	Hypothallial cells in μ	Sporangia in μ
1.	*A. lugeoni* Pf.	12–20 × 8–10	35 × 8	100 × 40–50
2.	*A. simanensis* N. Rao ..	23 × 8–12	12 × 6–9	104 × 39–52
3.	*A. floridanum* Johnson and Ferris.	33 × 14	....	84–109 × 52–67
4.	*A. zonatum* sp. nov. ..	13–18·2 × 10·4–15·6	13–15·6 × 10·4–13	130 × 65

A. zonatum, besides showing marked differences in the measurements of the vegetative thallus, is remarkable in possessing a zonated perithallium with sporangia whose dimensions surpass any of the *Archaeolithothamnium* species so far recorded from India. The specific name *zonatum* is therefore, accorded to these forms which are readily distinguished by their zonated perithallium with remarkably big and ovoid sporangia.

Archaeolithothamnium lakiensis sp. nov.

(Pl. XII, fig. 3.)

Diagnosis:

Thallus encrusting and strongly nodular; perithallial lattice very regular, compact and made up of squarish cells, sometimes vertical cell walls more prominent. Perithallium very massive, hypothallium scanty and observed with difficulty, absent in most cases. Sporangia ovoid, lenticular in vertical sections, arranged in rows.

Measurements:

Perithallial cells .. 7·8–10·4 μ × 7·8–10·4 μ
Hypothallial cells .. Absent ? not observed with certainty.
Sporangia .. 65–72·8 μ × 33–39 μ. Ovoid, about twice as long as broad, giving a lenticular aspect in longitudinal vertical sections, mostly 72 μ × 33·8 μ.

Description:

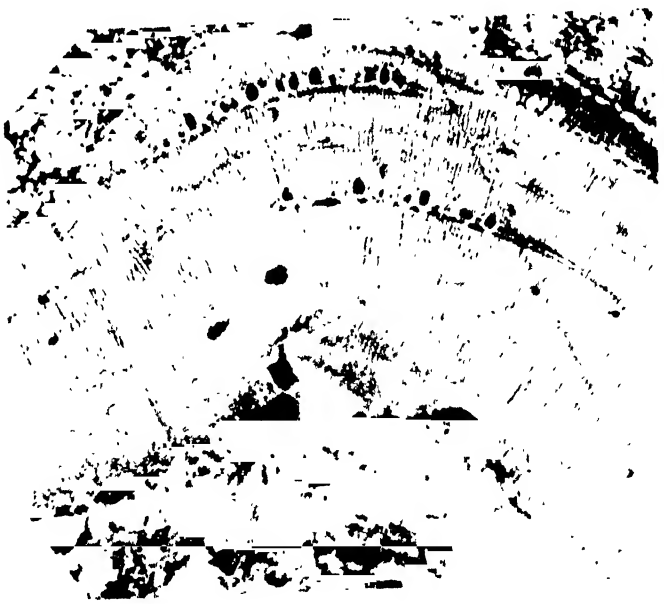
Thallus encrusting and strongly nodular. Thickness of the perithallium varies from 0·33 mm. (in primary thallus) to about 2·8 mm. (in a nodule). The general perithallium made up of a compact lattice of squarish cells mostly measuring 7·8 μ × 7·8 μ, while the cells of the bigger size 10·4 μ × 10·4 μ are generally observed near the fertile zones. Any structure referable to a branch is not known from this species. The sporangia are long ovoid, appearing lenticular in vertical sections and arranged in files. The sporangial rows are generally continuous. In the nodules as many as 20 or more such sporangial files may be present; in such cases these sporangial files are more or less regularly spaced, the smallest distance separating two adjoining rows being 33 μ.

Sporangia approximately twice as long as broad and in majority measure 72 μ × 33·8 μ. The presence of the hypothallium has not been noticed with

1

3

2



4

certainty though in one specimen some obliquely cut cells could be observed below the perithallium. In all others no hypothallium is noticed.

Comparisons:

A. lakiensis makes an approach more or less to the following forms known from India: *A. aff. provinciale* Pf., *A. ranikotensis* N. Rao and *A. nongsteinensis* K. S. Rao with respect to its sporangial measurements.

The present species approaches *A. aff. provinciale* described from Cretaceous of S. India with regard to the sporangial measurements (60–70 $\mu \times 30\,\mu$ in *A. aff. provinciale* while differing from it in having the perithallium made up of small and perfectly square cells (15–30 $\mu \times 7$–$10\,\mu$ in *A. aff. provinciale*; 7·8–10·4 $\mu \times 7{\cdot}8$–$10{\cdot}4\,\mu$ in *A. lakiensis*) and in the absence of the alternating zones of bigger and smaller cells in the protuberances which are described in *A. aff. provinciale* by Pia. He states (1936, p. 37), 'It may be pointed out, however, that it fairly resembles *Archaeolithothamnium provinciale* as described by Pfender. It is mainly distinguished from this species by the alternation of thicker and thinner cell strata described above. Pfender states positively with respect to the cells of the protuberances: 'Les rangées sont régulières et leur hauteur ne varie qu' insensiblement'.

A. ranikotensis N. Rao differs from *A. lakiensis* in having regularly ovoid sporangia of 42 $\mu \times 68\,\mu$ in size, in having comparatively bigger perithallial cells 8–10 $\mu \times 20$–$30\,\mu$ and in the presence of the hypothallial tissue with 'cells nearly square measuring 6 $\mu \times 8\,\mu$' (1941, p. 48).

Among the Assam forms of *Archaeolithothamnium*, *A. langrinensis* K. S. Rao and *A. archisporangia* K. S. Rao are ruled out by the shape of their sporangia, the former with trapezoid and the latter with sporangia having parallel lateral sides, flat base and arched roof.

A. nongsteinensis K. S. Rao differs in having considerably smaller sporangia (50 $\mu \times 25\,\mu$), presence of hypothallial cells 30 $\mu \times 10\,\mu$ and rectangular cells 20 $\mu \times 11\,\mu$ forming the perithallium. *A. hemchandri* K. S. Rao is also very different in possessing spherico-ovoid to nearly spherical sporangia (50–55 $\mu \times$ 40–45 μ) and the thallus with rectangular perithallial cells (10–12 $\mu \times 8$–$10\,\mu$) showing secondary hypothallium, though the primary hypothallium is not present.

One other species *A. gosaviense* Rothpl. shows certain similarities with the present form. *A. gosaviense* is similar in general appearance of the nodules and in abundance of the zones of sporangia in them. It is described as possessing cubic cells which would certainly appear almost squarish in sections. But it differs from *A. lakiensis* in having a very well developed (Pfender, 1926, p. 12) basilar hypothallium, and in the smaller size of the sporangia 60 $\mu \times 30\,\mu$.

Archaeolithothamnium nammalensis sp. nov.

(Pl. XII, fig. 4.)

Diagnosis:

Thallus encrusting and thin, running for several centimetres in length. Perithallial lattice less distinct, occasionally a little lobed or mammillated. An ill developed hypothallium present, small circular to ovoid sporangia seen in vertical sections and arranged in files among the rectangular perithallial cells.

Measurements:

Perithallial cells	.. 9·1–13 $\mu \times 10{\cdot}4 \times 14{\cdot}3\,\mu$
Hypothallial cells	.. 9·1–13 $\mu \times 9{\cdot}1$–$10{\cdot}4\,\mu$
Sporangia	.. 46–52 $\mu \times 31$–$39\,\mu$ ovoid, mostly 52 $\mu \times 33{\cdot}8\,\mu$.

Description:

Thallus very thin, generally 132–297μ wide, running for 2–3 cms. or more, occasionally nodulated to lodge the sporangial rows which are 2 to 3 in number. Perithallial tissue composed of an imperfect lattice of rectangular cells. The biggest nodule shown here (pl. XII, fig. 4) measures a little more than a millimetre and bears only two rows of sporangia separated by about 215μ. The sporangia as seen in vertical section are ovoid to circular, the latter aspect of the sporangia may be the result of the oblique plane in which the thallus and the sporangia are cut. Sporangia mostly measure 52$\mu \times$33·8μ. Hypothallium present, ill developed in most cases but is very well seen in one specimen (pl. XII, fig. 4).

Comparisons:

A. nammalensis offers a little comparison with *A. nongsteinensis* in general aspect of the thallus while it differs in the shape and size of the sporangia (circular to ovoid, 52μ × 33·8μ in *A. nammalensis*; ovoid, 50$\mu \times$25μ in *A. nongsteinensis*) and in having smaller cells in the perithallium and hypothallium (those in *A. nongsteinensis* being: perithallial cells 20$\mu \times$11μ, hypothallial cells 30$\mu \times$10μ) and in other minor details.

Appendix.

Table for the determination of *Archaeolithothamnium* species from India (based on Lemoine's classification).

1st Section. Tissue Homogeneous.

(*a*) Species crustaceous :

(1)	Perithallium	.. 12–20μ × 8–10μ
	Hypothallium	.. 35$\mu \times$8μ
	Sporangia	.. 100$\mu \times$40–50μ, ovoid
	Age and Locality	.. Danian, Trichinopoly. *A. lugeoni* Pfender.
(2)	Perithallium	.. Present
	Hypothallium	.. Absent
	Sporangia	.. 65$\mu \times$40μ ovoid
	Age and Locality	.. Danian, Trichinopoly. *A.* c.f. *lycoperdioides* (Mich) Lem.
(3)	Perithallium	.. 20–30$\mu \times$8–10μ
	Hypothallium	.. 6$\mu \times$8μ
	Sporangia	.. 68$\mu \times$42μ, ovoid to irregular
	Age and Locality	.. Palaeocene, Samana Range, Punjab. *A. ranikotensis* S. R. N. Rao
(4)	Perithallium	.. 20$\mu \times$11μ
	Hypothallium	.. 30$\mu \times$10μ
	Sporangia	.. 50$\mu \times$25μ, ovoid
	Age and Locality	.. Lower Eocene, Assam. *A. nongsteinensis* K. S. Rao.
(5)	Perithallium	.. 10–12$\mu \times$8–10μ
	Hypothallium	.. Absent
	Sporangia	.. 50–55$\mu \times$40–45μ. Spherico-ovoid to nearly spherical
	Age and Locality	.. Lower Eocene, Assam. *A. hemchandri* K. S. Rao.

(6) Perithallium .. 7·8–10·4 $\mu \times 7{\cdot}8$–10·4 μ
Hypothallium .. Absent (?)
Sporangia .. 65–72·8 $\mu \times 33$–39 μ, ovoid to lenticular
Age and Locality .. Palaeocene, Nammal Gorge, Punjab.
A. lakiensis sp. nov.

(7) Perithallium .. 9·1–13 $\mu \times 10{\cdot}4$–14·3 μ
Hypothallium .. 9·1–13 $\mu \times 9{\cdot}1$–10·4 μ
Sporangia .. 52 $\mu \times 33{\cdot}8$ μ, ovoid
Age and Locality .. Palaeocene, Nammal Gorge, Punjab.
A. nammalensis sp. nov.

(*b*) Species branched :

(1) Perithallium .. 8–12 $\mu \times 23$ μ
Hypothallium .. 6·2–9 $\mu \times 12{\cdot}4$ μ
Sporangia .. 93–104 $\mu \times 39$–52 μ, ovoid rectangular, vertical sides straight and parallel, the roof flat to slightly convex and base tapering to a point.
Age and Locality .. Palaeocene, Samana Range, Punjab.
A. samanensis S. R. N. Rao.

2ND SECTION. TISSUE SHOWING AN ALTERNATION IN THE HEIGHTS OF ROWS.

(1) Perithallium .. 15–30 $\mu \times 7$–10 μ
Hypothallium .. Absent
Sporangia .. 60–70 $\mu \times 30$ μ, ovoid
Age and Locality .. Danian, Trichinopoly.
A. aff. provinciale Pfender

(2) Perithallium .. 35–40–44 $\mu \times 22$–15–40 μ
Hypothallium .. ..
Sporangia .. 55 $\mu \times 44$ μ, trapezoid
Age and Locality .. Middle Eocene, Khasi Hills, Assam.
A. langrinensis K. S. Rao

3RD SECTION. TISSUE ZONATED.

(1) Perithallium .. 20–25 $\mu \times 20$–28 μ
Hypothallium .. Absent
Sporangia .. 60 $\mu \times 30$–35 μ Parallel sides, flat base and arched roof.
Age and Locality .. Lower to middle Eocene Khasi Hills, Assam.
A. archisporangia K. S. Rao.

(2) Perithallium .. 13–18·2 $\mu \times 10{\cdot}4$–15·6 μ
Hypothallium .. 13–15·6 $\mu \times 10{\cdot}4$–13 μ
Sporangia .. 130 $\mu \times 65$ μ, ovoid
Age and Locality .. Palaeocene, Nammal Gorge, Punjab.
A. zonatum sp. nov.

SUMMARY.

General remarks on the characters of the genus *Archaeolithothamnium*, together with its previous records in India, are made. Three new species of the genus discovered from the Laki beds exposed at the Nammal Gorge (32° 40′ : 71° 48′) in the Punjab Salt Range (Pakistan) are described. In the appendix a table for the determination of the Indian species of *Archaeolithothamnium* is given.

Acknowledgments.

I am deeply indebted to Prof. S. R. N. Rao for his invaluable guidance and for the material he put at my disposal. I am also thankful to the Scientific Research Grants Committee of the U. P. Government for a fellowship. My sincere thanks are also due to Shrimati Savitri Sahni of the Birbal Sahni Institute of Palaeobotany for library and laboratory facilities so kindly extended to me.

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Explanation of Plate.

Plate XII.

Archaeolithothamnium.

Fig. 1. *A. zonatum* sp. nov. Nearly vertical section through a thin crust showing two sporangia arranged in a continuous arched row. The two cell rows below it show somewhat squarish cells. ×50.

„ 2. *A. zonatum* sp. nov. Obliquely vertical section passing through the fertile zone, showing the zonated perithallium and the ovoid sporangia in the upper part. In the lower part the sporangia are seen cut somewhat crosswise. ×50.

„ 3. *A. lakiensis* sp. nov. Nearly vertical longitudinal section through a primary thallus showing lenticular sporangial rows. ×50.

„ 4. *A. nammalensis* sp. nov. Nearly vertical section passing through a nodule, showing the arched rows of circular to ovoid sporangia and the hypothallial tissue. ×50.

EVOLUTION AND DISTRIBUTION OF GLYPTOSTERNOID FISHES OF THE FAMILY SISORIDAE (ORDER: SILUROIDEA).

By SUNDER LAL HORA, *D.Sc., F.R.S.E., C.M.Z.S., M.I.Biol., F.A.S., F.Z.S.I., F.N.I., Director, Zoological Survey of India, and*
E. G. SILAS, *M.A., M.Sc.*

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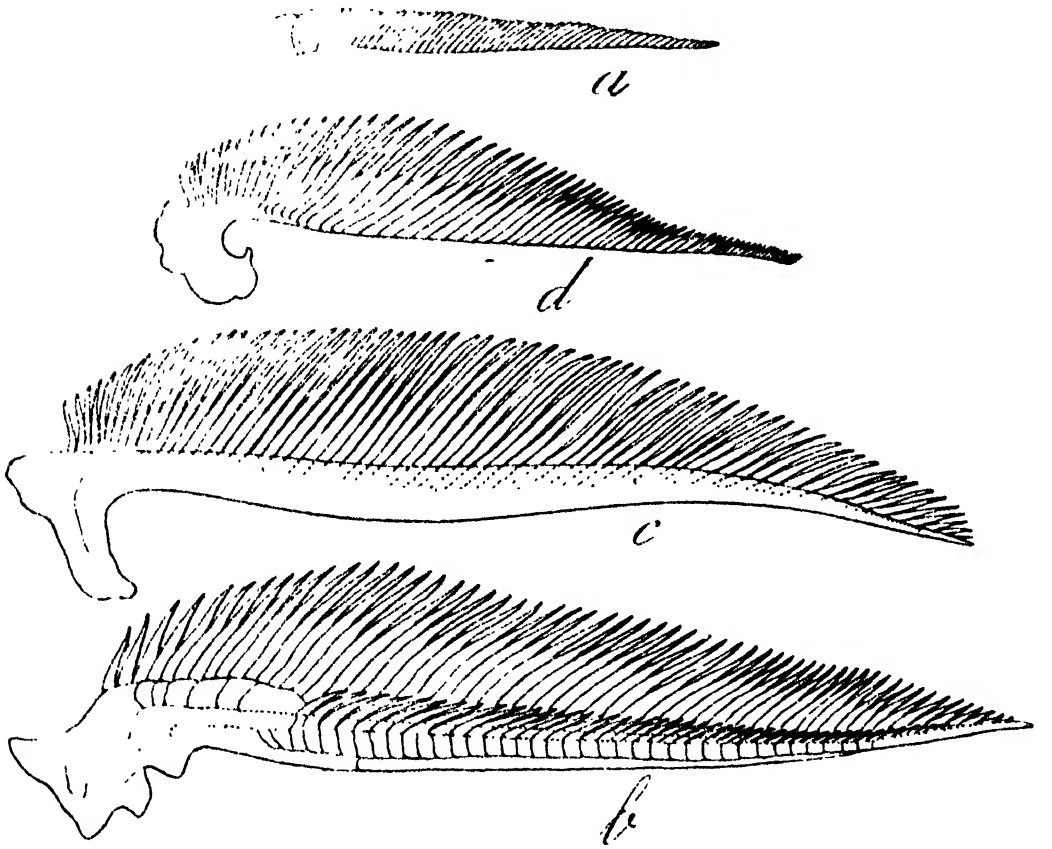
INTRODUCTION.

One of us (Hora, 1922, 1923) discussed the systematics of the Glyptosternoid fishes of the family Sisoridae nearly a generation ago and a great controversy has raged since then regarding the views expressed by him. Examination of the abundant material in the collection of the Indian Museum and the views of many eminent ichthyologists on the nomenclature and taxonomy of these fishes have enabled us (1951) to attempt a detailed revision of this remarkable association of fishes. We have now been able to recognise as many as 7 genera and 19 species pertaining to the *Glyptosternum*-group of fishes. The main diagnostic characters on which they have been separated are: (i) dentition (structure and arrangement of teeth); (ii) nature of gill-openings (whether restricted to the sides or extending to ventral surface); (iii) extent of pectorals in relation to the position of the pelvics; (iv) nature of labial groove (continuous or discontinuous); and (v) the number of rays in the pectoral and pelvic fins. Habituated as these fishes are to torrential waters and rocky streams, the adaptive significance of the above characters cannot be doubted. It is the purpose of this article to evaluate the significance of these characters in the evolution and adaptation of these genera, and to show how ecological conditions or geographical isolation have brought about a great diversity of form and structure among them.

GLYPTOSTERNOID GROUP: STRUCTURE OF THE FIRST RAY OF PECTORAL AND PELVIC FINS.

The name Glyptosternoid fishes is restricted to *Glyptosternum* McClelland and its closely allied forms, and does not include *Glyptothorax* Blyth, *Pseudecheneis* Blyth and similar other allied Sisorid genera. The fishes of the Glyptosternoid group can be readily distinguished from the other Sisorid fishes, which also live in rapid waters, by the absence of an adhesive apparatus in the thoracic region and by the complete segmentation or pinnate condition of the first ray of the pelvic and pectoral fins. In *Glyptosternum* McClelland (*sensu stricto*), 'the first ray of the pectoral and ventral fins soft and pinnate, giving off soft pointed cartilagenous

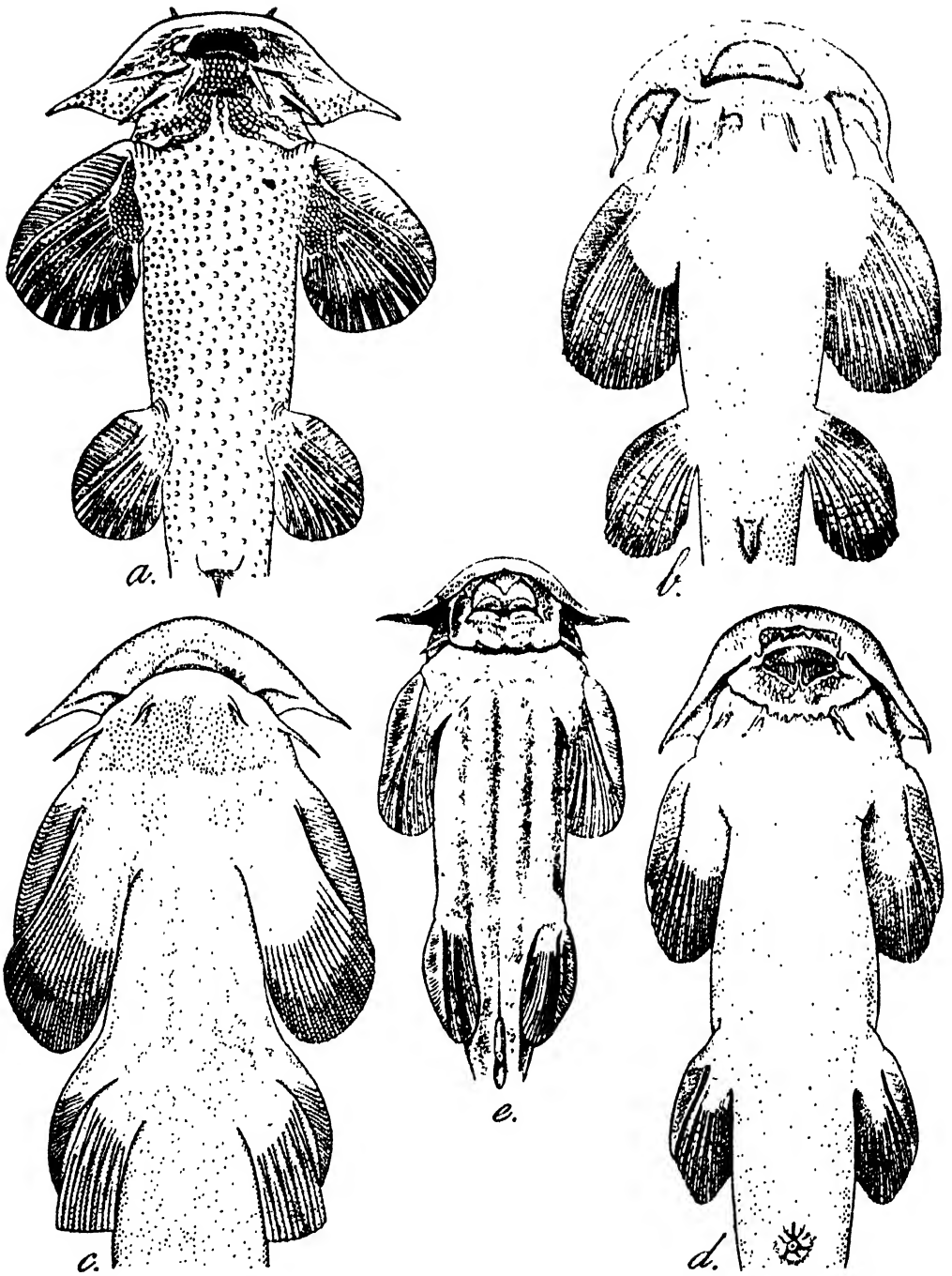
rays along the anterior margin; which are enveloped in the membrane of the fin' (McClelland 1842). In *Coraglanis* Hora & Silas,[1] *Glaridoglanis* Norman, *Euchiloglanis* Regan and *Myersglanis* Hora & Silas,[1] soft, pointed, cartilagenous rays are present, but the rays themselves are distinguishable, though segmented in part or wholly. In *Exostoma* Blyth, the rays are not pinnate but are completely segmented. In regard to the modifications of these rays, we have thus an evolutionary series from *Exostoma*-type of structure to the *Glyptosternum*-type, and there is little doubt that these modifications have an adaptive significance. The pinnae or the cartilagenous rays correspond externally to the ridges and



TEXT FIG 1. Internal structure of the outer ray of the pectoral spine in:
(*a*) *Exostoma labiatum*. (*b*) *Euchiloglanis hodgarti*. (*c*) *Coraglanis kishinouyei*.
(*d*) *Glyptosternum reticulatum*.

grooves of the skin on the ventral surfaces of these rays to which the function of adhesion has been transferred from the thoracic region. In this character, *Exostoma* is least specialised. In fact, Blyth (1860) in erecting this genus stated 'otherwise generally similar to *Glyptothorax*, but with no pectoral disk'. We also consider that the group of Glyptosternoid fishes, as defined above, originated from *Glyptothorax*-like ancestors under the stress of stronger currents and necessity for more efficient mechanism of adhesion. The segmentation of the spine makes it pliable to stresses in swift currents and its pinnate nature affords a greater adhesive area to be applied to the substratum along with flexibility.

[1] The descriptions of the new genera and species are under publication in the *Records of the Indian Museum*.



TEXT-FIG. 2. Ventral view of the Glyptosternoid fishes showing the nature of the labial-fold: (*a*) *Glyptosternum reticulatum*. (*b*) *Coraglanis kishinouyei*. (*c*) *Euchiloglanis hodgarti*. (*d*) *Oreoglanis siamensis*. (*e*) *Exostoma labiatum*.

LIPS AS ORGANS OF ADHESION: LABIAL FOLD CONTINUOUS OR INTERRUPTED.

Another character by which Blyth distinguished his *Exostoma* from *Glyptothorax* was the nature of the lips. He stated that in *Exostoma* 'Lips reflected and spread continuously round the mouth, so as to form a broad flat sucker'. In

species of *Glyptothorax*, the lips are papillated and serve as organs of adhesion (Bhatia, 1950). In species like *G. horai* Shaw and Shebbeare, the thoracic adhesive apparatus extends as far forwards as the lips. In the species of *Glyptothorax*, in which striated adhesive pads are developed on the under surface of the pelvic and pectoral spines, the adhesive organ on the chest is reduced. Thus to combat the effect of torrential currents, the lips as well as the pectoral and pelvic fin rays are both pressed into service for purposes of adhesion. Whereas in forms like *Exostoma*, *Oreoglanis* and *Myersglanis*, both the lips and the fin rays are equally useful for adhesive purposes, in *Glyptosternum*, *Coraglanis*, *Euchiloglanis* and *Glaridoglanis* the function of adhesion is more or less relegated to the fins and in consequence the labial fold is interrupted and the lips are not reflected and spread continuously round the mouth. They live in deeper waters of the main rivers of Central Asia where the swiftness of current does not affect them to the same extent as in small, shallow, torrential streams. As, owing to the position of the tooth-bands, the mouth cannot be completely closed in *Exostoma*, *Oreoglanis* and *Myersglanis*, the suctorial lips may have arisen as a respiratory adaptation so as to prevent the outflow of water through the mouth during the expiratory phase of respiration. Normally, during exhalation, most fishes keep their mouths shut but owing to the position of the tooth-bands, this is not possible in these fishes. The broad, reflected lips round the mouth now serve both at the time of exhalation and also when the fish wants to secure a firm hold to the substratum during floods. In both cases, the function of the expanded lips remains the same—adhesion.

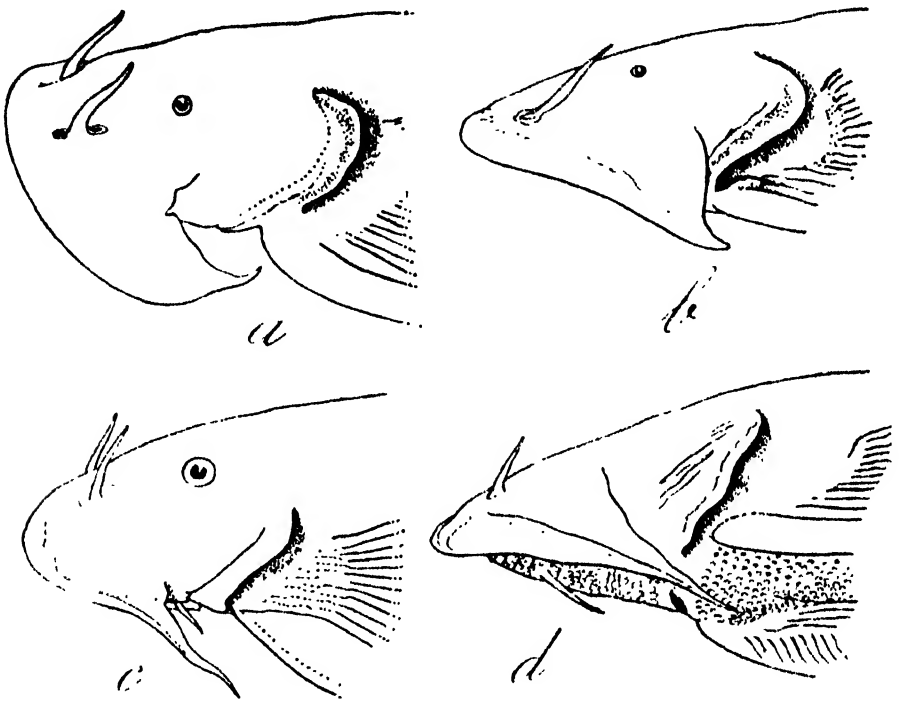
Inner rays of paired fins: Pressure-reducing device.

In specialised hill-stream fishes, it has been pointed out by one of us (Hora, 1930, p. 218), that the inner rays of the paired fins are used for pumping out leakage water from the ventral surface of the fish so as to reduce pressure on the ventral surface for ensuring perfect adhesion to the substratum. In forms, in which the first rays of the pectoral and pelvic fins have formed an efficient organ of adhesion or the currents are not so tempestuous, the need for pumping function is probably less and therefore the number of such rays remains small as in *Glyptosternum* (P. 1/11); *Coraglanis* (P. 1/13) and *Glaridoglanis* (P. 1/10). Pectorals do not overlap the pelvics in these genera and are separated from each other by a considerable distance. In *Exostoma*, where the function of adhesion is shared by the lips and the first rays of the paired fins, the number of branched rays in the pectoral fins is also less (P. 1/10 12) and the pectorals do not overlap the pelvics (exception, *E. yunnanensis* where the pectorals have 17 rays). Judging from the standpoint of functional morphology of the characters of forms like *Oreoglanis* and *Myersglanis*, they would appear to be better adapted, for a torrent life, for besides possessing adhesive fin rays and lips, they possess as many as 16–19 branched rays in the pectoral fins. The pectorals do not, however, overlap the pelvics. In ? *Oreoglanis macropterus* the pectorals overlap the pelvics thus converting the entire ventral surface into a sucker. In *Euchiloglanis hodgarti* (Hora), the pectorals just overlap the pelvics and the number of branched rays in the pectorals is 17. The increase in the number of branched rays in the paired fins and the extent of the pectorals in relation to the pelvics are highly adaptive modifications in hill-stream fishes.

Extent of Gill-openings: Restricted to above or Extending below base of pectoral.

With the exception of *Glyptosternum*, which is a Trans-Himalayan genus of deep, swift, rocky rivers, the gill-openings in all other genera are restricted to the dorso-lateral sides and do not extend to the ventral surface of the fish. In all fishes

that apply their ventral surface to some substratum, irrespective of the habitat they may live in, the lower portion of the gill-opening becomes non-functional and gets gradually closed up. The reduction of gill-openings in these fishes is further facilitated by the fact that the torrents are well-oxygenated and the fishes have



TEXT-FIG. 3. Nature of the Gill-openings in the Glyptosternoid fishes:
(*a*) *Coraglanis kishinouyei*. (*b*) *Euchiloglanis sinensis*. (*c*) *Exostoma vinciguerrae*. (*d*) *Glyptosternum reticulatum*.

developed gill-pouches to retain a certain quantity of water in the gill-chambers for respiration, like air in most air-breathing fishes. In species of the same genus, one finds that the extent of the gill-openings may vary when it is restricted to the dorso-lateral surface. This is, however, an evolutionary phase in the reduction of gill-openings to small openings well above the bases of the pectoral fins.

GEOGRAPHICAL DISTRIBUTION.

Before considering the above characters collectively as constituting genera and species, it is necessary to give the geographical distribution of the various forms. The following table and the accompanying map give the distribution pattern of the various species.

It will be seen that *Glyptosternum* is a trans-Himalayan genus with two well-defined species, one in the west (*G. reticulatum*) and the other in the east (*G. maculatum*). These two species may have had a common ancestral form when the trans-Himalayan portions of the Indus and the Brahmaputra had more connections. Now the two forms are isolated and have diverged from each other. *G. akhtari* is closely allied to *G. reticulatum*, a widely distributed and variable species, but has developed specific characters just as the Bamian Trout (*Salmo trutta orientalis*) became a distinct race in this river. There can hardly be any doubt that the ancestral form of *Glyptosternum* must have had been a *Glyptothorax*-like ancestor. The dentition, the mouth parts, etc., are of a less specialized nature.

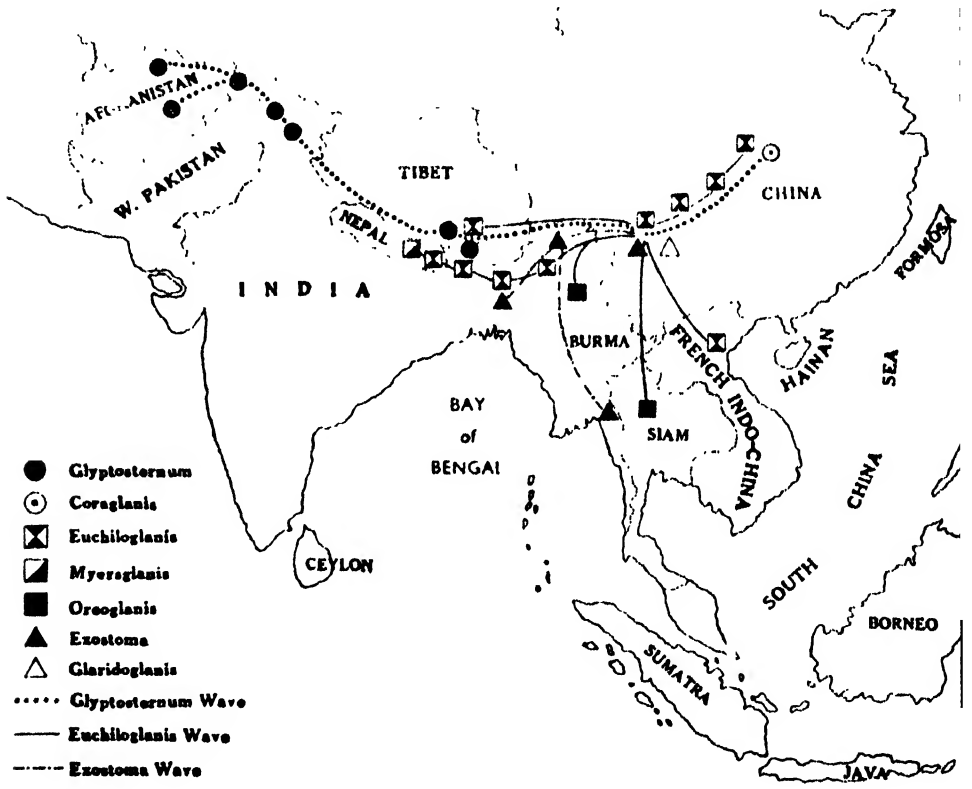
Scientific Name of Species.	Distribution of the Species.
Glyptosternum reticulatum McClelland	Harwan, Kolatse, Ladak, Sneena, Basgo, Leh, Pallagra in Kashmir; Chitral; Paghman and Surchab rivers in Afghanistan.
Glyptosternum maculatum (Regan)	Gangtse in Tibet; Sikkim.
Glyptosternum akhtari Silas	Bamian river, Oxus Water shed, Afghanistan.
Coraglanis kishinouyei (Kimura)	Chengtu and Kiating (Min River Drainage) Szechuen, China.
Euchiloglanis hodgarti (Hora)	Pharping, Nepal; Kurseong, Riyang and Rangbi rivers, Teesta Valley, Darjeeling; Rotung and Rening, Abor Country, Assam.
Euchiloglanis davidi (Sauvage)	Eastern Tibet.
Euchiloglanis myzostoma Norman	Lo-ma-Ho, tributary of river Mekong at Lamping, Yunnan, China.
Euchiloglanis feae Vinciguerra	Upper Burma (Tao' and Nga Kyankka Kyonkgue).
Euchiloglanis sinensis Hora & Silas	Locality undetermined, (most probably Yunnan, China).
Euchiloglanis macrotrema Norman	Ngoi-Tio, Col-des Nuages, Tonkin, Indo-China.
Myersglanis blythi (Day)	Pharping in Nepal.
Glaridoglanis andersonii (Day)	Hotha, Yunnan; Ponsoe, China.
? *Oreoglanis macropterus* (Vinciguerra)	Upper Burma, Kakhyan Hills, and Pazi, Mekong, Hispi State.
Oreoglanis siamensis Smith	River Kung near Doi-Anga, Siam.
Exostoma berdmoori Blyth	Tenasserim, Burma.
Exostoma vinciguerra Regan	Putao Plains, N.E. Burma, 'Catcin' Burma, Pazi Monghong, Hsipi State, N. Shan-States.
Exostoma stuarti (Hora)	Nam Yak River, Putao Plains, N.E. Burma.
Exostoma labiatum McClelland	Egar stream between Rening and Rotung, Abor Country, Assam; Lizo river (Tiza river) Naga Hills, Assam.
Exostoma yunnanensis (Tchang)	Yunnan, China.

Coraglanis from Szechuen, in its dentition and mouth parts, is similar to *Glyptosternum* but in the possession of more rays in the pectorals, it shows better adaptation for life in torrential streams. A further proof of this assumption is afforded by the fact that, whereas the gill-openings extend to the ventral surface in *Glyptosternum*, they are restricted to above the base of the pectoral spine in *Coraglanis*. There can be no doubt of the general affinities of the two genera while their divergences can be attributed to the ecological conditions under which they live at present, *Glyptosternum* in somewhat deeper rivers and *Coraglanis* probably in streams more liable to flooding. From the distribution pattern of the two genera, Yunnan would appear to be the centre of their origin and subsequent distribution to the west, and east during the Pleistocene.

Euchiloglanis, with six species, is distributed from eastern Tibet, Tista drainage in Eastern Himalayas, through Burma and Yunnan to Tonkin in Indo-China and to Szechuen in China. The tooth-bands, though somewhat restricted, are not very different from those of *Glyptosternum* and *Coraglanis* and the mouth parts are also similar. The Eastern Himalayan species, *E. hodgarti* (Hora), is perhaps the most highly specialized member of the genus. In this species, the pectorals overlap the pelvics and possess 17 branched rays. The gill-openings are greatly restricted. In *E. davidi* from Eastern Tibet, Yunnan and Szechuen the pectorals just reach the pelvics and the number of branched rays in the pectorals varies from 13 to 15. The gill-openings are greatly restricted. In other species from Yunnan, *E. myzostoma* and *E. sinensis*, the pectorals are separated from the pelvics by a considerable distance and the number of branched pectoral rays is 14 to 15 in *E. myzostoma* and 13 in *E. sinensis*. The gill-openings are greatly restricted in *E. myzostoma* and extend to the base of the pectorals in *E. sinensis*. In Upper Burma,

we have *E. feae* in which the pectorals do not overlap the pelvics, but possess 15 branched rays and gill-openings are very much restricted. In the Indo-Chinese species, *E. macrotrema*, the pectorals do not overlap the pelvics but possess 16 branched rays and the gill-openings extend to the base of the pectorals.

Of the six species of *Euchiloglanis*, two are known from South China (Yunnan), one from Eastern Tibet, Yunnan and Szechuen, one from Upper Burma, one from Eastern-Himalayas and one from Indo-China. Judging from the number of branched fin rays in the pectorals, the Eastern Himalayan and the Indo-Chinese species are better specialized for life in torrential streams whereas species in the intermediate regions with Yunnan as the centre show various gradations and combinations of characters. Like *Glyptosternum* and *Coraglanis*, in *Euchiloglanis*



TEXT-FIG. 4. Map showing the present day distribution of the Glyptosternoid Fishes and the probable routes of migration.

all the teeth in both the jaws are conical and pointed but the teeth in the upper jaw form a slightly bilobed band which is not produced at the sides. From a zoogeographical point of view, it would seem probable that *Euchiloglanis* was evolved from the supposed ancestral stock of the *Glyptosternoid* fishes later than *Glyptosternum* and *Coraglanis* because of their very much more extensive distribution and became distributed within a narrow belt comprising Eastern Tibet, Upper Burma and Eastern Himalayas towards the west and to Szechuen and Indo-China in the north-east and south-east respectively.

In Nepal, we have the genus *Myersglanis*, which combines the teeth characters of *Euchiloglanis*, but shows an advance in its adaptive modifications. Though the pectorals do not overlap the pelvics, the number of branched rays in the

pectorals is 16-17. The gill-openings extend to the base of the pectorals which is a somewhat less specialized character. The greatest advance is in the fact that the lips are continuous and reflected round the mouth to form an adhesive disk. Thus in the Eastern Himalayas and Nepal, where tectonic movements are known to have been very severe during the Pleistocene, we witness the evolution of *Euchiloglanis hodgarti* and *Myersglanis blythi* from a common ancestral form of the less-specialized *Euchiloglanis*-type.

In the remaining three genera of Glyptosternoid-group, all teeth in both jaws are not conical and pointed. The Yunnanese genus *Glaridoglanis* shows a very high specialization of teeth, combined with a large number of primitive characters. Though the teeth in the upper jaw form a band which is not produced backwards at the sides, they are greatly compressed, with broad emarginate or notched apices. The less specialized characters are:

(1) Pectorals and pelvics separated by a considerable distance.
(2) Pectorals with only 11 branched rays.
(3) Lips not continuously reflected round the mouth.

In the characters of gill openings, however, it is highly specialized, for they are restricted above the bases of the pectoral fins. This is a monotypic genus restricted to Yunnan. It would seem probable that it originated as an independent unit from the earliest ancestors of the Glyptosternoid stock.

Oreoglanis of Siam is not different from *Myersglanis* of Nepal, except that in the former all teeth in the lower jaw are not conical and pointed, the anterior being much larger with slender bases and free end expanded into a truncate-spatulate shape with inner surface slightly hollow. Like *Myersglanis*, the pectorals do not overlap the pelvics but possess 17 to 18 branched rays. The gill-openings are greatly restricted and the lips are continuously reflected round the mouth to form a suctorial disk. *Oreoglanis* would thus seem to us to be a specialization of *Euchiloglanis* in the same way as *Myersglanis*.

Special attention must be invited here to *Exostoma macropterus* Vinciguerra from Upper Burma. In this species, the pectorals overlap the pelvics and possess 19 branched rays. The gill-openings extend to the base of the pectorals but the lips are continuously reflected round the mouth to form a suctorial disk. One of us (Hora, 1923) had noted on a previous occasion that all the teeth are not pointed and conical, but that material is now lost. Until the type material in the Genova Museum is examined and the exact systematic position of this species determined, we have provisionally retained it in the genus *Oreoglanis*. In any case, it appears to be a specialized *Euchiloglanis* in the direction of *Myersglanis* and *Oreoglanis*.

The last group of five species referred to the genus *Exostoma* Blyth has a number of primitive characters and a number of highly specialized features. The less specialized characters are:

(1) The outer rays of the pectoral and pelvic fins are segmented but not pinnate.
(2) The pectorals do not overlap the pelvics and possess 10 to 12 branched rays. (In one exception 17.)

The specialized characters are:

(1) Teeth in upper and lower jaws arranged in two well separated patches.
(2) Teeth in both jaws oar-shaped: flattened distally.
(3) Lips continuously reflected round the mouth to form a sucker.
(4) Gill-openings restricted to the dorso-lateral surface.

Three species of *Exostoma* are known from Upper Burma; one from Assam hills and Eastern Himalayas, and one from Yunnan. This is a compact group which seems to have independently evolved at a much later stage and got dispersed from Yunnan only to Burma and North-East India.

As a result of the above discussion, there seems little doubt that the original home of the Glyptosternoid fishes was Yunnan and that the various genera and species originated in a series of waves at such intervals as the tectonic movements in this region occurred. We can, however, account for three likely waves.

Glyptosternum-wave.—Trans-Himalayan, spreading from Yunnan to the Brahmaputra, Indus and Oxus river-systems (*Glyptosternum*) and Szechuen (*Oreoglanis*). As the dentition and the mouth parts of these two genera are least specialized we regard them as the earliest Glyptosternoid fishes though both are specialized in the structure of the outermost fin ray of the paired fin and *Oreoglanis* is further specialized in regard to the gill-openings, which are restricted above the bases of the pectorals, and in having larger number of pectoral rays. From the point of view of their function to secure better hold on rocks in swift currents, both these characters are adaptive.

Euchiloglanis-wave.—This wave also originated in Yunnan and spread both towards the west as far as Eastern Himalayas and the east to Szechuen and Indo-China. The six species of *Euchiloglanis* show great diversity of structure among themselves. As a consequence of the same wave, but probably after some time lag, we got the genus *Oreoglanis* (*O. siamensis*) in Siam and (*? O. macropterus*) in Burma and *Myersglanis* in Nepal. The inter-relationships of these forms from the evolutionary point of view have been referred to above already.

Exostoma-wave.—This wave is at present restricted to Yunnan, Upper Burma and the Assam Hills and would thus appear to be of a later origin than the earlier waves. It would seem to have started also from Yunnan.

Glaridoglanis is endemic in Yunnan and would appear to have developed from the original Glyptosternoid stock last of all. Tendency towards differentiation of teeth had already started with the origin of the *Exostoma*-wave.

Time of evolution of the Glyptosternoid Group.

In the following table the main diagnostic features of the genera and species of the Glyptosternoid group are given in order to show at a glance that no one character can give us an idea of any straight line of evolution of these forms. Repeated divergences and convergences have, as a rule, formed the basis of great diversity of form and structure that we notice today.

In considering the time taken for the evolution of this group, two main considerations must be borne in mind—firstly, the ecological conditions under which these fishes live demand immediate adaptive features for survival in torrential streams; secondly, during the late Tertiaries and particularly the Pleistocene, tectonic movements were very frequent and of a high magnitude. With the frequent uplift of the Himalayas and associated ranges of mountains, the streams were being constantly rejuvenated thus subjecting the animals living in them to constant strains and stresses with the result that there was a rapid evolution of new forms within a comparatively short interval. This is what seems to have happened in the case of the Glyptosternoid group of fishes. It seems probable that the entire group evolved during the Pleistocene period and our reasons for this supposition are the following:—

(1) Though *Glyptothorax* Blyth, the likely ancestral form of the *Glyptosternum*-group, is widely distributed in the Indian and the Indo-Malayan regions and beyond, the Glyptosternoid fishes have a comparatively much restricted distribution.

(2) Homalopteridae, for which one of us (Hora, 1949) has opined Pliocene as the probable age, has spread to the extreme part of Peninsular India on the one hand and to the Malayan Archipelago on the other. There are several species in Peninsular India which correspond to the species found in the Malayan region and their dispersal probably

TABLE I.

Salient Characters of the Glyptosternoid fishes.

No.	Name of species.	Pectorals overlapping pelvics.	Gill openings extend to			Teeth conical and pointed.	Labial groove continuous.	No. of branched rays in the pectorals.
			(1) Above base of pectoral.	(2) Opposite base of pectoral.	(3) Ventral surface.			
1	*Glyptosternum reticulatum* McClelland	..	..	..	X	X	..	11
2	*Glyptosternum maculatum* (Regan)	..	..	..	X	X	..	11
3	*Glyptosternum akhtari* Silas	..	..	..	X	X	..	11
4	*Oreoglanis kishinouyei* (Kimura)	..	X	..	..	X	..	13
5	*Euchiloglanis hodgarti* (Hora)	X	X	..	..	X	..	17
6	*Euchiloglanis davidi* (Sauvage)	..	X	..	..	X	..	13 15
7	*Euchiloglanis myxostoma* Norman	..	X	..	..	X	..	13-15
8	*Euchiloglanis feae* (Vinciguerra)	..	X	..	..	X	..	15
9	*Euchiloglanis sinensis* Hora and Silas	..	..	X	..	X	..	13
10	*Euchiloglanis macrotrema* Norman	..	..	X	..	X	..	16
11	*Myersglanis blythi* (Day)	..	..	X	..	X	X	16 19
12	*Glaridoglanis andersonii* (Day)	..	X	..	..	..	..	10
13	? *Oreoglanis macropterus* (Vinciguerra)	X	..	X	..	..	X	19
14	*Oreoglanis siamensis* Smith	..	X	..	..	..	X	13
15	*Exostoma berdmorei* Blyth	..	X	..	..	..	X	10
16	*Exostoma vinciguerrae* Regan	..	..	X	..	..	X	10-12
	Exostoma stuarti (Hora)	..	..	X	..	..	X	10 12
17	*Exostoma labiatum* (McClell.)	..	..	X	..	..	X	12
18	*Exostoma yunnanensis* (Tichang)	..	X	..	..	..	X	17

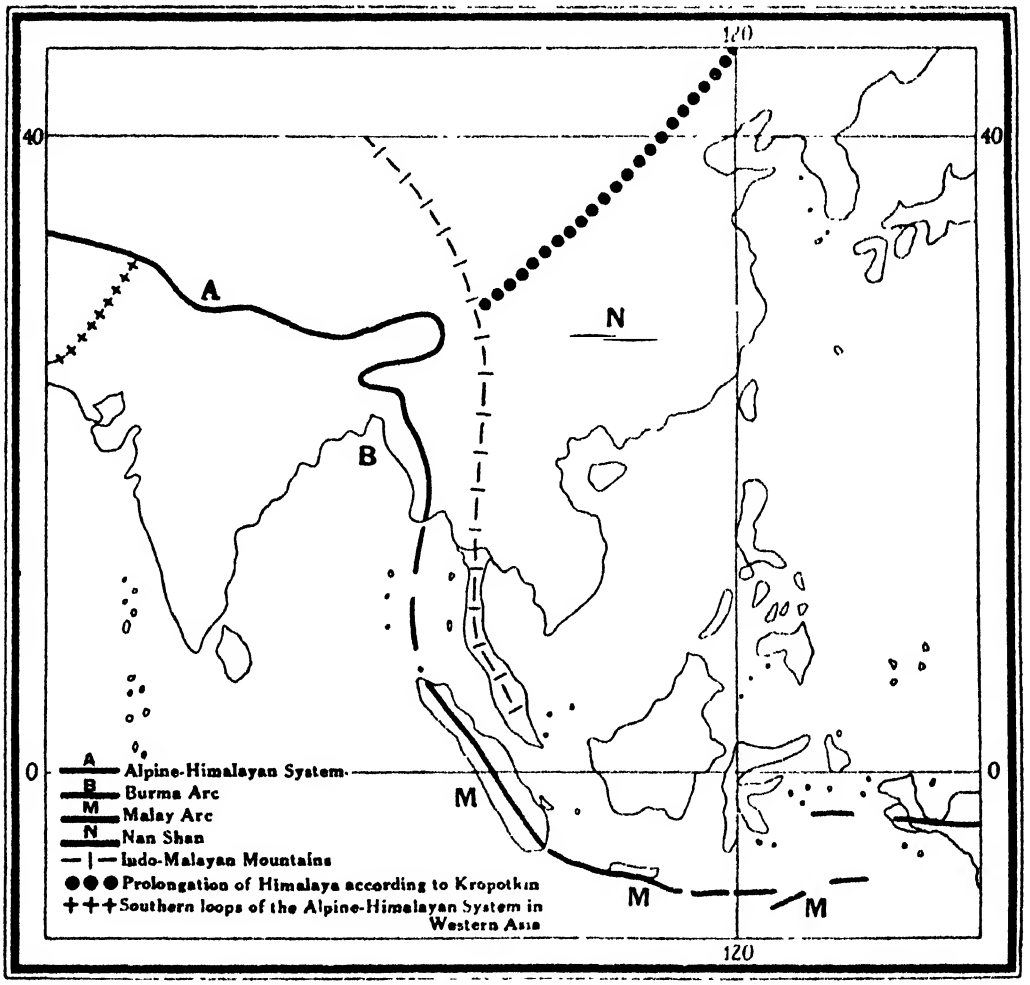
took place during the very late Pliocene or Pleistocene. The Glyptosternoid group, on its distributional records, seems to be younger than the Homalopteridae.

(3) Taking into consideration quick rate of evolution of species (Zeuner, 1948), it is possible to account for the evolution of the entire group within about a million years. Forms living in torrents, undergoing rejuvenation with every successive orogenic movement, probably had a faster rate of speciation than even terrestrial forms.

To understand the causes of quick evolution and dispersal, it is necessary to consider some geological facts about the Pleistocene geography of Yunnan and of the adjacent countries.

Pleistocene Geology of Yunnan and the neighbouring countries.

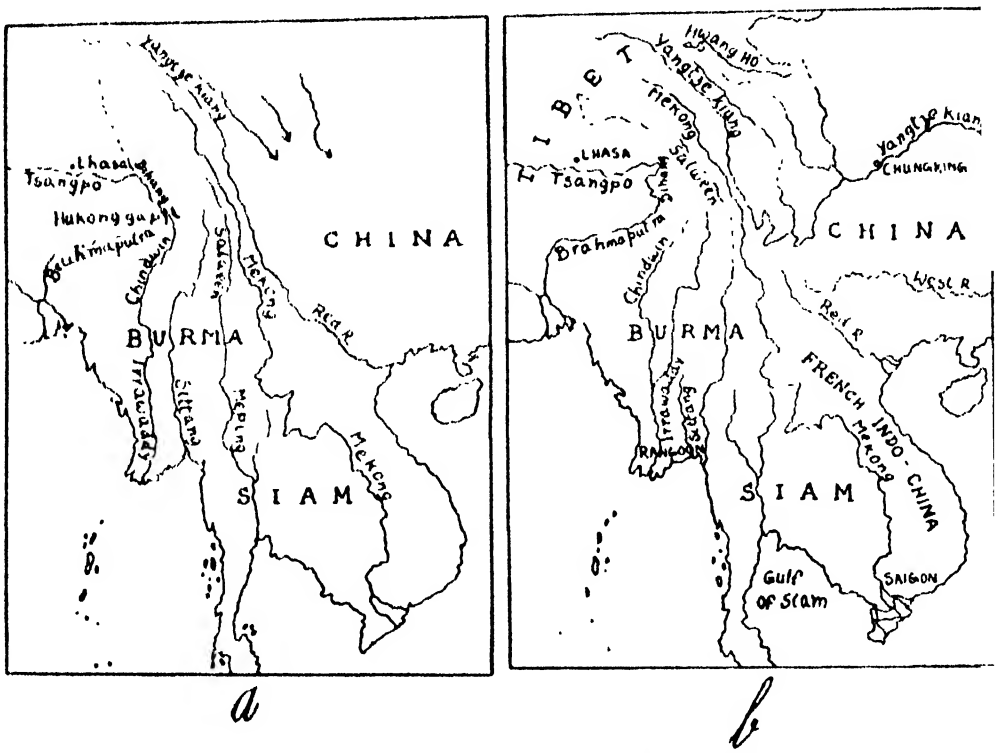
Gregory and Gregory (1923), and Gregory (1925) have given a very lucid account of some of the recent geological changes in South Eastern Asia, with a view to make clear the geographical relations and the evolution of the mountains and river systems in this part of the continent.



Text-fig. 5. The Alpine-Himalayan System and their Hypothetical Eastern connections. (Modified from Gregory, J. W., and Gregory, C. J., 1923.)

The direct Himalayan uplift and the later crustal upfolds have adversely affected the Chinese Tibet and South-Western China, *viz.*, Yunnan. Different views have been expressed regarding the eastern continuity of the Alpine-Himalayan uplift. The altaids which are of a much earlier time and date with the Hercynian systems of Europe, are represented at present by the Indo-Malayan mountain trend cross the Chinese Tibet on lines approximately north and south and continue southward as the Indo-Malayan mountains. This older system is

supposed to have stemmed the eastward extension of the direct Himalayan uplift. In the region of the Chinese Tibet where the Himalayas and the Altaid Systems meet, crustal movements have produced very complex topographical features. As a result of the resistance offered by the Altaid mountains, the Himalayan movements became resolved into two factors, one resulting in a chain of intense folding across Southern China known as the Nan Shan and the other in the uplift of the Burmese-Malay Arc, which pass through Western Burma to Malay and thence to the islands of the Archipelago, such as, Sumatra, Java, New Guinea and to Papua. The dissected plateaus of Western Yunnan are parts of the eastern uplift of the direct Himalayan movements. In Yunnan these movements have occurred in the foot hills and have been planed down by the rivers. Post-Himalayan movements have been particularly felt in Yunnan and its immediate vicinity. These movements and the resulting habitudinal variations are supposed to have been



TEXT-FIG. 6. Map showing (*a*) The Post-Himalayan River System of South-East Asia. (*b*) Existing River System of South-East Asia. (After Gregory, J. W., 1925.)

responsible for the differentiation of the Glyptosternoid-group of fishes from the ancestral stock. The Pleistocene orogenic movements, which affected the drainage systems in South-Eastern Asia, also helped in the dispersal of their aquatic fauna. It would seem that to the Glyptosternoid fishes, which radiated having Yunnan as the centre, the main Himalayan trend in the west, the Burmese Arc in the south and the Nan Shan trend in the east acted as the principal migratory highways.

In order to understand how this distribution was effected, it is essential to know the changes that took place in the main river systems in South-Eastern Asia during this period. A vivid account of the various changes in the river systems are thus given by Gregory and Gregory (1922, pp. 172–173).

"The southern drainage after the close of the Himalayan movements was discharged by five (four) main rivers: (1) the Dihang, which carried the drainage from the Tsangpo and much

of the western Tibet southward as the Lower Irrawaddy; (2) the Upper Irrawaddy in north-eastern Burma which was probably not then connected to the Lower Irrawaddy but discharged to the sea as the Sittang River, near Pegu, through the broad valley between the Shan Plateau and Lower Irrawaddy; (3) the Salween which then probably continued through the Meping and Menam rivers to the Gulf of Siam at Bangkok; (4) the Mekong, which doubtless discharged as at present, across Tonking, though along its present course; and (5) the Yangtze, which was probably continued from its great bend at the Shikhu through the valley of Kienchwan (Chien-chuan Chou) past Tali and through the Red River to the Gulf of Tonking near Hanoi. This simple river system was broken up by subsidences probably consequent of the reaction from the Himalayan compression. One subsidence made the valley of Assam which diverted the Dihang through the Lower Brahmaputra to the Ganges; this change beheaded the Chindwin, which till then had been the main stream of the Irrawaddy. That river, however, was compensated for the loss of its Tibetan head-stream by capturing the drainage of north-eastern Burma, by beheading the Sittang River, through the reach around the end of the Sagaing range. The Salween was diverted by the formation of a series of young gorges westward to the Gulf of Martaban. The development of the Yangtze gorges enlarged that river by the capture of the former Tibetan tributaries of the Red River." Gregory and Gregory (1922, pp. 172–173).

The agency which enabled the rivers of Yunnan to cut their canyons has been regarded generally as a regional uplift, but Gregory and Gregory have shown that the same results can be obtained by regional subsidence of the areas under consideration. Whatever may be the correct explanation of the deep valleys of south-western Chinese rivers, from the point of view of distribution of fishes, it is noteworthy of remark that the original Salween which is supposed to have discharged through the Meping and Menam rivers to the Gulf of Siam had its eastern branch diverted towards the west which now discharges into the Gulf of Martaban and is known as the Salween, while its eastern branch joined the Mekong River and its waters were thus diverted towards the east. All the rivers of the west of Salween had their head waters beheaded by more eastern rivers. These facts indicate the probable directions of subsidence from south-western China, and enable us to understand the distribution of the torrential fishes.

Conclusion.

Thus it seems that the Glyptosternoid fishes, like the Homalopteridae, got dispersed along certain routes aided by the exigences of nature. As explained above, their distribution has been effected in a series of waves, which probably synchronized with the glaciation periods of the Pleistocene when precipitation was higher and rate of evaporation low thus giving rise to more perennial torrential streams in the hilly regions. It is also evident that wherever and whenever changes in the environment occurred, specific differentiations set in the group, thus giving rise to adaptive variations discussed above.

Since the distribution of the Glyptosternoid fishes is at present restricted to within eastern Nepal and Assam Hills in the west, to Siam and Tenasserim in the south, to Szechuan and Yunnan in the north-east and the Indus and Oxus Systems in the north-west it is reasonable to surmise that the evolution and distribution of the Glyptosternoid fishes took place during the Pleistocene and that the great taxonomic variation observed among them is the result of the late Himalayan orogenic movements playing upon the older Altaid mountains and getting resolved along the lines of distribution of the Glyptosternoid fishes.

Summary.

Fluctuations in ecological conditions and geographical isolation have brought about a great diversity of form and structure in the Glyptosternoid-group of Catfishes of the family Sisoridae, which live in the torrential streams of certain parts of south-eastern Asia. The adaptive significance of the modifications of characters, such as (*a*) the structure of the first ray of the pectoral and pelvic fins; (*b*) the lips as organs of adhesion; (*c*) inner rays of paired fins as a pumping mechanism; (*d*) the relative extent of the gill-openings; (*e*) the nature of the

dontition; and (*f*) the extent of the pectorals in relation to the pelvics, is discussed and the directiveness of evolutionary trends in these fishes indicated. An account of the geographical distribution of the various genera and species is given and discussed. Evidence for the evolution and distribution of the Glyptosternoid fishes during the Pleistocene is adduced. Geological data, as well as the present day distribution of the group, indicate that the Glyptosternoid fishes originated somewhere in the region of Yunnan in south-western China. Later orogenic movements, such as the Himalayan uplift and the consequential river capture in south-eastern Asia, facilitated the dispersal of these fishes along certain mountainous highways to far off places. As a result of subsequent long isolation and continued orogenic disturbances, speciation took place with the formation of new genera and species within comparatively restricted geographical areas. Thus the great variation observed among the Glyptosternoid fishes seems to be the result of the late Himalayan orogenic movements playing upon the older Altaid mountains and getting resolved along the lines of the present-day distribution of these fishes.

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SYMPOSIUM

ON

HISTORY OF SCIENCES IN SOUTH ASIA

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PREFATORY NOTE

One of the objects of the National Institute is ' To promote and maintain a liaison between science and letters '. The Symposium on the *History of Sciences in South Asia* shows the earnestness of the Institute to maintain such a liaison. In fact, the development of science, apart from that of humanities, is not happy for human welfare in the long run. As this was the first attempt to bring together historians, oriental scholars and scientists, some sharp differences of opinion, especially about the dates of the ' Source Material', were evident but such differences were resolved by agreeing to certain dates as an *interim* measure and to ensure uniformity of treatment. In this connection, reference may be made to Appendix IX, in which are reproduced from *Nature* a critical review of the papers of the Symposium by Dr. Joseph Needham and, a note, elucidating certain points in it by the undersigned and a postscript by Dr. Needham. It was decided by the National Institute that, as the full papers required considerable revision, a summary of the papers presented at the Symposium and discussions arising therefrom only should be published. It is hoped that the material presented in the present account will serve a useful purpose, for, as Dr. Needham has pointed out ' the study of the history of science in India remains enthralling '.

Mathura Road,
New Delhi 1,
27th November, 1951.

S. L. HORA,
President,
National Institute of Sciences of India.

A BRIEF ACCOUNT OF THE SYMPOSIUM ON THE HISTORY OF SCIENCES IN SOUTH ASIA, HELD IN DELHI, 5–7 NOVEMBER, 1950.

The idea of holding a Symposium on the 'History of Sciences in South Asia' was first mooted by Dr. D. S. Kothari, one of the Secretaries of the National Institute of Sciences of India. He at the outset thought it desirable to discuss the matter with Prof. A. Wolsky, Principal Scientific Officer of the U.N.E.S.C.O. Science Co-operation Office for South Asia, in Delhi, in view of the work that his office was doing for the progress of science in India and elsewhere. Prof. Wolsky welcomed the porposal and offered wholehearted co-operation, and assured Dr. Kothari that if the National Institute undertook to initiate the proposal to hold the Symposium, it could count on the active support of the U.N.E.S.C.O. Science Co-operation Office for facilities and financial assistance.

Dr. Kothari and Dr. Wolsky then discussed about the arrangements to be made for holding the Symposium and decided on the following preliminary details :—

(1) The National Institute of Sciences should form an *ad hoc* Sponsoring Committee which in its turn would appoint a Convener (or an executive secretary) for making plans in consultation and in collaboration with the U.N.E.S.C.O. Science Co-operation Office. The Sponsoring Committee should preferably consist of individuals rather than of representatives of different learned bodies.

(2) The Symposium should be a study group of not more than 20 to 25 scholars who should survey the existing contributions to the history of science from South Asia and also attempt to correlate the advances made in different branches and the social implications of the scientific developments.

(3) There should be some background material or working papers for the guidance of the scholars at the Symposium, which might be obtained from the Secretariat of the International Union for the History of Sciences and possibly some more help and materials from a person who might be approached to come and attend the Symposium as an expert consultant. Dr. Wolsky mentioned that he had already approached Prof. Joseph Needham for the purpose and that he would also write to Prof. Bernal if they could give some directions as to the agenda and working of the Symposium.

(4) Each delegate should be required to submit a report on the progress on the history of sciences in his particular branch in his own country. These reports should contain not only the achievements but also a list of published materials and the possible sources of other materials which might be tapped for further intensive study. An attempt should also be made to get some special papers which might show the influence of the achievements of scientists in the East on the development of sciences in the West and *vice versa*.

The general plan of work was then decided to be as follows :—

(1) The Symposium should be preceded by a short opening session where two lectures on the general aspects on the history of sciences should be given and interested people should be invited to attend the session. After the inaugural meeting, the Symposium group consisting of about 20 scholars should sit consecutively for at least three days and discuss papers on the History of Sciences and also deliberate on ways and means of intensifying the study of the History of Sciences in

South Asia. In this task the participants of the Symposium, grouped into three classes, as historians, scientists and research scholars on the history of sciences, should sit in separate groups, and again jointly, for formulating practical recommendations.

(2) At the close of the Symposium there should be another short general session, while even in the course of the session of the Symposium there should be two or three popular lectures in the evening.

(3) Delegates should be invited from Ceylon, Burma, Thailand and Indonesia and it was likely that reports from those countries would cover all the branches in a single report. There might be one or two scientists in China who might as well be induced to come and take part in the proceedings so as to make the discussions as comprehensive as possible.

(4) It was felt that better success of the Symposium would be achieved if active national committees or societies were formed in various countries and steps taken for a planned preparation of a history of the development of sciences in the countries of South Asia. This would stimulate scholars, interested in the history of sciences, to prepare for the forthcoming International Union for History of Sciences to be held in Amsterdam in August, 1950, so that more attention could be drawn to contributions from this part of the world.

Prof. Kothari and Dr. Wolsky then made some preliminary selection of scholars to be approached for contributing to the Symposium and it was thought advisable to wait till the Council of the National Institute of Sciences would approve of the suggestions. Afterwards details of the arrangements would be worked out after consultation with the U.N.E.S.C.O. Science Co-operation Office which, as Dr. Wolsky suggested, would act as secretariat for the Symposium. Dr. Kothari proposed to hold an exhibition of some of the materials having bearing on the History of Sciences. He also suggested that the University of Delhi might be approached for giving facilities for holding the Symposium in their premises.

The proposal of holding the symposium and the decisions arrived at by Dr. Kothari and Dr. A. Wolsky were placed before the Council of the National Institute of Sciences of India, at their meeting on 3rd March, 1950. The Council approved the proposal, and as suggested by Dr. Wolsky, a Sponsoring Committee was appointed, with power to co-opt additional members, to organize the holding of the Symposium under the auspices of the Institute, in collaboration with the U.N.E.S.C.O. Science Co-operation office for South Asia.

The Sponsoring Committee, appointed by the Institute, held two sittings, one in March and the other in September, 1950. At their first meeting, a preliminary discussion took place of the theoretical assumptions on which the idea of a Symposium on the History of Sciences in South Asia was based, and a programme of work was tentatively fixed for the meeting, which was:—

2000 B.C. (*circa*)—From Mohenjo Daro Civilization (i.e. Indus Valley Civilization) to A.D. 1857, i.e., beginning of the British Rule, to be detailed under the following heads:—

(1) (*a*) Chronology of the achievements; and
(*b*) Defining the periods of achievements.
(2) Life Stories of the pioneers.
(3) Contacts with outside on countries' own initiative or by the adventurous trips of foreigners.
(4) General history of those periods with stress on social conditions.
(5) Impact of the discoveries of the scientists on military strategy of the kings and on the general living conditions, like town planning, public health, agriculture, transport and industries.

(6) (*a*) Library sources of manuscripts; and
(*b*) Important centres of ancient scientific research as possible locations to trace manuscripts.[1]
(7) Promotion of study of History of Sciences.
(*a*) An organized body of scholars with a programme of work to meet frequently and contribute papers; and
(*b*) Funds for engaging research scholars and endowing fellowships.

The Committee also made a suggestion that the following categories of scholars should be invited to participate in the Symposium:—

(1) Scientists who have studied the progress of ancient scientific thought and methods;
(2) Historians who have made studies of special periods of history relating to the scientific achievements; and
(3) Scholars (linguists and historians) in Ancient History who have made special studies of ancient records, inscriptions, manuscripts, etc.

The Sponsoring Committee also suggested that a press note announcing the holding of the Symposium be issued in April, which should be followed by a circular to learned bodies in India, Ceylon, Malaya, Burma, Indonesia and Pakistan, seeking their co-operation by contribution of papers from historians and scientists who are connected with them and by the supply of list and locations of source-materials. Personal requests were also to be made to individuals known to be in a position to contribute to the Symposium.

In accordance with the decision, a press-note detailing the objects of the Symposium was published in important papers in India and invitations were sent to important cultural and scientific societies in India. The response was encouraging, both from India and abroad, including Indonesia, Burma, Ceylon and Thailand. As the adhering body to the International Union of the History of Sciences, the Government of India, Department of Scientific Research, have accorded their approval to the Symposium being held under the auspices of the National Institute of Sciences in collaboration with the U.N.E.S.C.O.

At the second meeting of the Sponsoring Committee, arrangements for holding the Symposium were further discussed, which related to its administration, such as, fixing of final dates for the Symposium, accommodation of representatives, travelling fare of delegates, scientific institutions to be invited, and the estimated total expenditure for holding the Symposium. At this meeting, a local Reception Committee was constituted, and the subscription of its members was fixed at Rs.5 per person.

It may be mentioned that it was the original intention of the Sponsoring Committee to hold the Symposium in the latter part of June, 1950, when it was expected to have the presence of Dr. Joseph Needham, who was engaged in the writing of a History of Sciences in China, would come to India for the purpose as an expert consultant. The expectation did not materialize as Dr. Needham's pre-occupations did not allow him to come to India. The final arrangements for holding the Symposium were complete only by the end of the year, and it was held, in Delhi, from November 5 to 7, 1950 (*vide* Programme of meetings. Appendix I). The meetings were held in the rooms of the University of Delhi, and the authorities of the University, the Vice-Chancellor and the Dean of the Faculty of Science, offered hospitality to the participants. Scientists and historians from various parts of India participated in the discussions and several scientific societies were also represented by delegates. Indonesia and Thailand were represented by Dr. Prijohutomo and Mr. P. Rochanapurananda respectively,

[1] Apart from manuscripts, there are epigraphical and archaeological sources all over in South Asia.

who came to India especially to participate in the Symposium. Besides the contributors, there were 30 observers representing 12 learned bodies. A list of participants is given in Appendix II. Messages of good wishes were received from a number of historians of science from other countries. It was the first time in India that scholars devoted to humanities and sciences met together to trace the History of Sciences. The contributors agreed that History of Sciences was eventually the history of civilization and human mental evolution and that a collaboration between the historians and scientists would lead to fruitful results.

The U.N.E.S.C.O. office, under the able guidance of Dr. Wolsky, had circulated to the intending participants mimeographed copies of the papers that had been received from oriental scholars and scientists for reading at the Symposium. When scientists and scholars arrived for the opening session, it was evident to all of them that considerable controversy was likely to arise in connection with the fixing of dates of the important ancient texts, especially of manuscripts of pre-Christian era. In order to tide over this difficulty, the participants of the Symposium considered it desirable to appoint a Chronology Committee from among them. A Chronology Committee was then appointed and they met and discussed the chronology of ancient texts at length, and decided on a chronological table basing mainly on Winternitz's *History of Indian Literature* (*vide* Appendix III). They also recommended the dates that were decided upon should be taken as a working hypothesis for the discussion of papers of the Symposium. This was accepted by all.

The participants of the Symposium then elected Sectional Chairmen and Rapporteurs for respective sections for conducting various Sectional meetings (*vide* Appendix IV).

The Symposium was opened under the Chairmanship of Dr. S. L. Hora, President-Elect of the National Institute of Sciences of India, for 1951, and Director, Zoological Survey of India, who gave a short address congratulating the organizers and detailing the objects of the Symposium (*vide* Opening Remarks Appendix V).

Papers contributed to the Symposium (Appendix VI) revealed the rich heritage of the people living east of Arabia and also discussed the decline of learning among those people. No momentous technical revolution took place in the countries of the East, though their knowledge travelled to Europe (mostly *via* Arabia) and helped the people of the West to progress with technical improvements and inventions on a very revolutionary scale. The papers were followed by discussions regarding the references that had been quoted, the dates assigned to them and the interpretations given of the texts. The general approach was also considered a topic for discussion a number of times.

The papers, presented at the Symposium, were classified under five headings, for convenience of discussion, as in the International Congress for the History of Sciences. As the number of participants was small, Sectional meetings were held one after the other and everyone took part in each Sectional session. This led to good interchange of ideas about developments in different branches. A summary of the papers and some of the more important points raised in the discussions are given in Appendix VII.

In the afternoon of the second day, there was an open session, where general discourses took place on History of the Biological Sciences, History of the Physical Sciences and Historical Aspects of the Development of Sciences. There were also two popular lectures.

After the discussion of the papers, there was a general discussion on the teaching of History of Sciences. Suggestions were made for extension lectures at the Universities, dealing with scientific developments from historical point of view. Endowment of chairs and funds for research on the subject were considered to be of urgent importance.

In the concluding session, resolutions were adopted to the effect that (*a*) a National Group affiliated to the International Union for History of Sciences be founded in each of the participating countries of South Asia; (*b*) a Board under the National Institute of Sciences of India be constituted for the study of History of Sciences. A Committee was appointed to bring into existence the National Group of India which was also entrusted with the task of going into the suggestions received at the Symposium regarding the formation of the National Group, organization of teaching and research and other general topics (*vide* Appendix VIII).

Finance

The total expenses of holding the Symposium amounted to Rs.10,036, covering several items of expenditure, including the travelling allowances of delegates. The major portion of them was borne by the U.N.E.S.C.O. and a very small portion by the National Institute of Sciences of India. The expenses for 'At Home' were met jointly by the Reception Committee, U.N.E.S.C.O. and the University of Delhi.

Acknowledgments

At the conclusion of the Symposium, thanks were recorded to the authorities of the University of Delhi for giving facilities for holding the Symposium at the University Buildings, and for giving accommodation to the delegates. Thanks were also recorded for the organizers of the Symposium as well as to the U.N.E.S.C.O. Science Co-operation Office for South Asia, Delhi, for their co-operation and financial assistance and to all those who contributed to the success of the Symposium.

APPENDIX 1

PROGRAMME OF MEETINGS

SUNDAY, NOVEMBER 5, 1950.

10 a.m.	*Business Meeting.* Election of Sectional Chairmen. Election of Sectional Rapporteurs. Adoption of the Agenda of the Symposium.
10-30 a.m. to 12-30 p.m. ..	Section I. History of Mathematics, Astronomy, Physics, Geography and Geology. *Discussion of papers*
2-30 to 4-30 p.m. ..	Section II. History of Chemistry, Mineralogy, Pharmacy and Biology. *Discussion of papers.*

MONDAY, NOVEMBER 6, 1950.

9-30 a.m. to 12-30 p.m. ..	Section III. History of Applied Sciences, Technology and Engineering. Section IV. History of Medicine. *Discussion of papers.*
2-30 to 4-30 p.m. ..	Open Session: (*a*) Address of welcome by Chairman of Reception Committee. (*b*) Messages. (*c*) Address by the President-Elect of the National Institute of Sciences of India. (*d*) Discourses on— History of Biological Sciences (Dr. S. L. Hora). History of Physical Sciences (Prof. N. R. Dhar). Historical aspects of Development of Science (Prof. R. C. Majumdar).
4-30 p.m.	At Home.
6 p.m.	Popular lecture: Traditional knowledge and scientific understanding (Dr. S. L. Hora).

TUESDAY, NOVEMBER 7, 1950.

9-30 a.m. to 12-30 p.m. ..	Section V. General problems (historical approach) methods and philosophy of science. *Discussion of papers.*
2-30 to 4-30 p.m. ..	Discussions on— (1) Teaching of the History of Sciences. (2) Organization for study of the History of Sciences. Adoption of Report to the National Institute of Sciences of India.
5-30 p.m. ..	Popular lecture (Prof. N. R. Dhar).

APPENDIX II

LIST OF PARTICIPANTS

Altekar, A. S., M.A., Ph.D. *Professor of Ancient History and Head of the Department of Culture, Patna University, Patna.*

Bagchi, P. C., M.A., D.Lit., F.A.S. *Director, Vidya-Bhavana, Vishva-Bharati, Santiniketan, W. Bengal.*

Chakravarti, N. P., M.A., Ph.D. *Director-General of Archaeology, India (on leave); 16 Tughlak Road, New Delhi.*

Chatterji, S. K., M.B., D.T.M , Ph.D. *Chemical Examiner to the Government of West Bengal, Chemical Department, Medical College, Calcutta.*

Chhabra, B.Ch., Ph.D. *Government Epigraphist for India, Ootacamund, S. India.*

Dhar, N. R., D.Sc., F.N.I. *Professor of Chemistry, Allahabad University, Allahabad.*

Dixit, K. R. *Professor of Physics, The Institute of Science, Bombay.*

Dutta, P. C., Lt.-Col., O.B.E., F.R.C.S.(E). *Director, Medical Services, Punjab (India), Simla.*

Hora, S. L., D.Sc., F.R.S.E., C.M.Z.S., F.Z.S.I., M.I.Biol., F.A.S., F.N.I. *Director, Zoological Survey of India, Jabakusum House, 31 Chittaranjan Avenue, Calcutta.*

Hossain, M., M.A. *Department of History, Muslim University, Aligarh.*

Kothari, D. S., M.Sc., Ph.D., F.N.I. *Scientific Adviser to the Government of India, Ministry of Defence, New Delhi.*

Majumdar, G. P., Ph.D., F.N.I. *Head of the Department of Biology, Dacca University, Ramna, Dacca.*

Majumdar, R. C., M.A., Ph.D., F.A.S. *Ex.-Principal, College of Indology, Banaras Hindu University. 1 Bepin Pal Road, Kalighat, Calcutta—26.*

Majumdar, R. C., Dr.Phil.Nat., F.N.I. *Professor of Physics, Delhi University, Delhi.*

Prijohutomo, P. *School for Police, Sukabumi, Java.*

Raghavan, N. G. S., Major, M.B.B.S., *Director, Malaria Institute of India, 22 Alipore Road, Delhi 2.*

Ranganathan, S. R., M.A., Ph.D. *Professor of Library Science, University of Delhi, Delhi 1.*

Rahman, A. *Central Laboratories for Scientific and Industrial Research. P.O. Lallaguda, Hyderabad, Deccan.*

Ray, P., M.A., F.N.I. *Palit Professor of Chemistry, Calcutta University, 92 Upper Circular Road, Calcutta 9.*

Rochanapurananda, P. *Department of Science, Ministry of Industry, Maharaj Road, Bangkok, Thailand.*

Saran, P., M.A., Ph.D. *Department of History, Delhi University, Delhi 1.*

Satyanarayanamurti, G. V., M.B., B.S. *Additional Professor of Medicine and Paediatrics, Andhra Medical College, Visakhapatnam, S. India.*

Seshadri, T. R., M.A., Ph.D., F.N.I. *Professor of Chemistry, Delhi University, Delhi 1.*

Shukla, K. S., M.Sc. *Department of Mathematics and Statistics, Lucknow University, Lucknow.*

Singh, Dr. Amarjit, *Department of Physics, Delhi University, Delhi.*

Singh, A. N., D.Sc. *Head of the Department of Mathematics and Statistics, Lucknow University, Lucknow.*

Ukil, A. C., M.B., M.S.P.E., F.S.M.F., F.A.S., F.N.I., *Ex-Principal, Calcutta Medical College; 67 Dhurrumtollah Street, Calcutta.*

Varma, S. R. *Director of Horticulture, P.E.P.S.U., Patiala.*

Wadia, D. N., M.A., D.Sc., F.G.S., F.A.S., F.N.I. *Geological Adviser to the Atomic Energy Commission, Ministry of Natural Resources and Scientific Research, Government of India, Room No. 191-A, North Block, New Delhi.*

Wolsky, Dr. A. *U.N.E.S.C.O. Science Co-operation Office for South Asia, University Buildings, Delhi 1.*

Yin, H. C. *U.N.E.S.C.O. Science Co-operation Office for South Asia, University Buildings, Delhi 1.*

APPENDIX III

CHRONOLOGY COMMITTEE

The appointment of a Chronology Committee at the outset was necessitated by the fact that though authenticity of the claims of ancient Indian achievements in scientific field went mostly unchallenged, scientists and historians present at the opening session of the symposium in respect of chronology of texts and scientific developments held divergent views.

The Committee consisted of :

Dr. R. C. Majumdar (Chairman)
Dr. A. S. Altekar (Member)
Dr. P. C. Bagchi ,,
Dr. S. L. Hora ,,
Dr. D. S. Kothari ,,
Dr. A. N. Singh ,,

This Committee met on 5th November, 1950, and after discussing the matter at length, recommended that the following chronological table should be taken as a working hypothesis:—

Age of the Ṛgveda	..	2000 B.C.–1500 B.C.
Age of Saṁhitās and Brāhmaṇas		1500 B.C.– 800 B.C.
Age of the old Upaniṣads	..	900 B.C.– 500 B.C.
Caraka	..	100 A.D.
Caraka Saṁhitā (Kernel of)	..	100 A.D. but being enlarged in later times.
Suśruta Saṁhitā ..	..	200 A.D.–500 A.D.
Vedāṅga Jyotiṣa (Present text)		500 B.C.
Śulbasūtras ..	..	500 B.C. and later.
Dharmasūtra ..	..	600 B.C.–200 B.C.
Mahābhārata Manusmṛti Rāmāyaṇa	..	200 B.C.–200 A.D.

Adopted by the General Meeting of the Symposium on 7-11-1950.

S. L. Hora,
Chairman of the Meetings.

APPENDIX IV

LIST OF SECTIONAL CHAIRMEN AND RAPPORTEURS

The following Sectional Chairmen and Rapporteurs for conducting various sectional meetings were appointed on 5th November, 1950, by the participants of the Symposium before the opening session:

Section I.

Mathematics, Astronomy, Physics, Geography and Geology.
Chairman : Dr. A. N. Singh. *Rapporteur :* Dr. K. S. Shukla.

Section II.

Chemistry, Mineralogy, Pharmacy and Biology.
Chairman : Dr. S. L. Hora. *Rapporteur :* Dr. G. P. Mujumdar.

Section III.

Applied Science, Technology and Engineering.
Chairman : P. Rochanapurananda. *Rapporteur :* Mr. A. Rahman.

Section IV.

Medicine.

Chairman : Dr. A. C. Ukil. *Rapporteur :* Dr. G. V. S. Murty.

Section V.

General Problems, Methods and Philosophy of Science.
Chairman : Dr. R. C. Majumdar. *Rapporteur :* Dr. A. S. Altekar.

APPENDIX V

OPENING REMARKS BY DR. S. L. HORA, CHAIRMAN OF THE SYMPOSIUM, ON 5-11-1950

It is very often said that 'History repeats itself'. Events have shown that such is sometimes the case. It follows, therefore, that for forecasting the future of a nation, a sound study of its past history is often a very useful guide. Science cannot be an exception to this general truism. One can build solidly the future development of science of any country only on the foundations of its traditional knowledge and achievements. It may sound like a paradox, but it is true all the same, that more you wish to look into the future, the greater must be your effort to dig into the past. The scientific achievements of any country, when thoroughly sifted and evaluated according to modern standards, can be an index to its past glory, cultural heritage and human values. Scientific thought is only one aspect of human life and its development or suppression depends, during any one period, on other circumstances affecting human life, particularly peace or war. The study of the History of Sciences can, therefore, serve two main purposes. Firstly, the trends of development or evolution of our past achievements can guide us to the possibilities for the future and we can thus plan accordingly. Secondly, it helps to complete our history as a whole by elucidating actions and reactions of scientific achievements on other phases of our lives, such as religion, philosophy, culture, material prosperity, industrial or agrarian developments, etc. The organizers of the present Symposium have, therefore, done a great service to India by holding it in the historic city of Delhi and thereby bringing to limelight the achievements of South Asia, which has long been regarded as the cradle of Human Civilization.

'Science is nothing but the finding of unity,' says Swami Vivekananda. That also is the goal of all the United Nations Organizations. Let us then seek unity among warring nations in the study of science—its past history and likely future achievements. If the history of sciences has to subserve this noble purpose, its study must be free from personal or racial prejudices because you cannot have a clear vision of anything through jaundiced eyes. Any nation can be rightly proud of its past achievements, but it should not be oblivious of the achievements of other nations. Friendships can be cemented only on mutual understanding and not on biased judgements. Science is international and let a scientific approach to all our problems be our guiding principle. The study of the History of Sciences, by providing a background of past events, will help us to fix true scientific principles for our everyday life.

APPENDIX VI

LIST OF PAPERS PRESENTED AT THE SYMPOSIUM ON THE HISTORY OF SCIENCES IN SOUTH ASIA

Section I

Mathematics, Astronomy, Physics, Geography and Geology.

Mr. K. S. Shukla. Chronology of Hindu achievements in astronomy.
Dr. K. R. Dixit. The history of Indian astronomy.
Dr. D. N. Wadia. Geological knowledge in ancient and mediaeval India.
Dr. A. N. Singh. Chronology of Hindu achievements in Mathematics.

Section II.

Chemistry, Mineralogy, Pharmacy and Biology.

Dr. S. L. Hora. Zoological knowledge with special reference to fish and fisheries in India before 225 B C.
Prof. P. Ray. The History of Chemistry in India.
Dr. G. P. Majumdar. The History of sciences in India from pre-Vedic times to eighteenth century A D.
Prof. N. R. Dhar. India's contribution to the chemical knowledge.

Section III.

Applied Science, Technology and Engineering.

Mr. P. Rochanpurnananda. The History of technical achievements in Thailand.

Section IV.

Medicine.

Dr. G. V. Satyanarayanamurty. A historical and chronological survey of the practice of hygiene and medicine in India from antiquity.
Dr. A. C. Ukil. The History of Indian medicine from ancient times to the eighteenth century.
Dr. S. K. Chatterji. Legal medicine ; its study and practice in India (from historical point of view).

Section V.

General Problems, Methods and Philosophy of Sciences.

Mr. A. Rahman. Social factors in the history of sciences in India.
Dr. P. C. Bagchi. Indian sciences in the Far East.
Dr. A. S. Altekar. A periodwise and critical survey of India's achievements in the scientific field.
Dr. R. C. Majumdar. Scientific achievements of the ancient Hindus ; chronological and sociological background.
Dr. Prijohutomo. Indonesian cultural history until the seventeenth century.
Mr. A. Rahman. The History of sciences and some problems of teaching.
Dr. A. Singh. A history of sciences course for undergraduates.

OTHER PAPERS RECEIVED

Dr. R. V. Seshaiya. Ancient Indian ideas of human development.
Mr. N. N. Chatterjee. Ancient India's contributions to geology and mineralogy.
Mr. A. K. Yegnanarayana Aiyer. Dairying in ancient India.
Dr. Mrs. Bani Chatterji. Musical science and scientific relations between East and West from the historical point of view.
Dr. P. M. Mehta. The medical man and his ideals in the golden age of Āyurveda.
Lt.-Col. B. L. Raina. The study of medical history in India.
Mr. J. K. Dholakia. Progress of sciences in South Asia before the eighteenth century.
Dr .K. K. Datta. Impact of industrial revolution on India's economy.

APPENDIX VII

SUMMARIES OF PAPERS AND GISTS OF DISCUSSIONS

(Prepared by Dr. Amarjit Singh[1]*)*

Section I. Mathematics, Astronomy, Physics, Geography and Geology

Chairman .. Dr. A. N. Singh.
Rapporteur .. Mr. K. S. Shukla.

Mr. K. S. Shukla. *Chronology of Hindu achievements in Astronomy.*

Mr. Shukla stated that Astronomy was originally developed in India for determining the times for Vedic rituals, and that subsequently it outgrew its original purpose and was cultivated for its own sake. He proceeded to give the following periodwise survey of these developments.

Vedic Astronomy (*c.* 2500 B.C. to *c.* 1000 B.C.): Views expressed in the Aitareya-Brāhmaṇa on the rising and setting of the sun indicate that the Vedic Hindus were aware of the sphericity of the earth. The sun's yearly motion was well known and was believed to be the cause of the seasons. In the Ṛg Veda the sun's annual course has been described as a 'twelve spoked wheel', the reference being probably to the 12 signs of the zodiac. The moon was studied with reference to 27 *nakṣatras*, forming so many constellations in the path of the sun and the moon. The time was reckoned on the basis of a solar year containing 12 lunar months and an intercalary month, every third year.

The Vedāṅga period (*c.* 1000 B.C. to *c.* 500 B.C.): The Vedāṅga Jyotiṣa is the earliest work which deals exclusively with Astronomy. It was meant to be a handbook for the priest engaged in the performance of Vedic rituals. It gives a glimpse of the primitive Astronomy of the Hindus and shows that at that remote period the Hindus considered Astronomy as a separate subject of study. This work contains a study of the months, years, *muhūrtas*, risings of *nakṣatras*, *yogas*, full moon and new moon, days, seasons, equinoxes and *ayanas*, which fall in a cycle of five solar years.

The unknown period (500 B.C. to A.D. 500): References to the last half of this period show that considerable work was done. However, works of this period are not available, probably having been discarded because they did not use the place value system of writing numbers. The new system was universally adopted about the end of the fifth century A.D. Some of the important astronomical works were, however, recast in the new style. Examples are, the *Sūrya-siddhānta*, the *Romaka-siddhānta*, the *Puliśa-siddhānta*, the *Pitāmaha-siddhānta*, *Vasiṣṭha-siddhānta* and the *Pañcha-siddhānta* of Varāhamihira which summarizes all the previous five.

A.D. 500–1200: This was a period of great activity and progress. Numerous Astronomical works were written of which the following are important examples.

The *Āryabhaṭīya* (A.D. 522) of Āryabhaṭa I. It is a small work setting forth principles of Mathematics and Astronomy. It uses a new system of notation for expressing numbers in verse and a new scientific division of time. It introduces certain alterations in the revolution numbers of the planets. It states that the earth rotates round its axis. It explains planetary motion on the basis of an epicyclic theory, different from that of the Greeks. It gives a correct interpretation of the eclipses and methods for calculating the times of their occurrence.

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[1] The Council of the National Institute of Sciences of India are grateful to Dr. Amarjit Singh for preparing summaries of papers and gists of discussions. (*Editor.*)

The *Brahma-sphuta-siddhānta* (A.D. 628) of Brahmagupta. In this treatise on Astronomy the teachings of the five *siddhāntas* and of Āryabhaṭa I have been criticized and several astronomical elements and rules have been modified.

The *Laghu-mānasa* (A.D. 932) of Mañjula. This manual of Astronomy is marked for its brevity and conciseness of expression. It is the first work to make use of the differential of a function. It states the lunar correction called evection in its modern form.

The *Siddhānta-śekhara* of Śripati (A.D. 1039). This work gives rules relating to (i) the correction for the equation of time due to the obliquity of the ecliptic and (ii) the correction to the east-to-west line determined from the shadow of the gnomon.

The *Siddhānta-śiromani* of Bhāskara II (b. 1114). This is the last and the best work of this period. The subject matter and the literary qualities of composition of this work have rendered it to be an outstanding work on Hindu Astronomy. This work is regarded as a standard text book on Hindu Astronomy even today.

A.D. 1200–1700: After the time of Bhāskara II, not much progress in Astronomy was made in Northern India. The Astronomers generally engaged themselves either in introducing refinements in the existing theoretical methods and almanac-making or in writing commentaries on works written in the previous period. Little advance seems to have been made in practical Astronomy.

The Astronomers of the South, notably Kerala, made certain notable contributions to Mathematics. They devised better methods of calculation, used processes akin to differentiation and integration, obtained expansions of trigonometric functions in infinite series, and made refinements in Astronomical methods.

Discussion. Dr. R. C. Majumdar objected to the dates ascribed to the Vedic period and to the Vedāṅga Jyotiṣa. Dr. A. S. Altekar pointed out an error in the interpretation of a Vedic passage. Mr. K. S. Shukla agreed to modify the paper in the light of the discussions. (The dates in the above summary are from the modified paper sent in by Mr. Shukla.)

DR. K. R. DIXIT. *The history of Indian astronomy.*

Dr. Dixit discussed the development of Astronomy in India, in the framework of the following three periods.

Vedic period (6000 B.C. to 1600 B.C.).[1] In the time-reckoning used in this period, the months were lunar, the year solar and an extra month was added every third year. No definite distinctions were made between *nakṣatras* and planets. *Śatapatha-Brāhmaṇa* mentions that the *krittikās* (pleiades) always rise due East. From the known rate of precession of the equinoxes, this can be used to fix the date of that text as 3000 B.C.

Vedāṅga Jyotiṣa (1600 B.C. to 600 B.C.). This period is characterized by three tracts: (1) the Ṛgveda Jyotiṣa, (2) the Yajurveda Jyotiṣa, and (3) the Atharvaveda Jyotiṣa. These tracts give empirical rules which relate to the determination of the duration of the day at the time of the winter and summer solstices and the interval between these two. This second set of rules enabled Mr. Dixit to arrive at the conclusion that these Vedāṅga Jyotiṣa texts must have been composed at about 1400 B.C. and at some place situated between the latitudes 34° 46′ N. and 34° 55′ N. According to this calendar, a period of five solar years is taken as a *yuga*. During this period the sun and the moon complete 5 and 67 revolutions respectively. The Atharvaveda Jyotiṣa which must have been composed much later contains besides the rules already mentioned some Astrological information. Some non-astronomical books which belong to this period contain references to items of astronomical importance such as the retrograde motions of the planets and their conjunction with each other and the sun and the moon.

[1] The dates accepted by the Symposium are given in Appendix III.

During the *Siddhānta* period (600 B.C. to A.D. 1800) a large number of books were written on Astronomy. All these books give methods of calculation for obtaining mean positions of the sun, the moon and the planets; and the time of the solstices, equinoxes and eclipses. The ancient five *siddhāntas* belong to this period: They are (1) the *Pitāmaha*, (2) the *Vaśiṣṭha*, (3) the *Pauliśa*, (4) the *Sūrya*, and (5) the *Romaka*. The first three *siddhāntas* are allied to the Vedāṅga Jyotiṣa system, while the *Romaka-siddhānta* has a close resemblance to the work of the great astronomer Hipparcus, who lived about 150 B.C. The *Sūrya* system is based on the *Kalpa* hypothesis. The *Kalpa* or *Yuga* is a period of time—probably the least time—which is an integral multiple of the periods of revolution of the five planets, the sun and the moon. The *siddhāntas* give methods for calculating the mean positions of the sun, the moon and the planets. Their true positions were calculated from their mean positions by two additional corrections.

The next important book is the *Āryа-siddhānta* of Āryabhaṭa (born in A.D. 477). In addition to genuine topics pertaining to Astronomy, this book deals with topics like, ratio and proportion, areas of triangles and circles, and volumes of solids and spheres. This book makes use of trigonometrical sines and gives the ratio of the circumference of a circle to its diameter as 3·1416. Āryabhaṭa was followed by Varāhamihira (b. A.D. 505) and Brahmagupta (b. A.D. 598), both of whom have written their own *siddhāntas*, Varāhamihira mentions some periodic comets and also describes their path, duration of their visibility and the time of their reappearance. According to Mr. Dixit, it was Brahmagupta who invented the *Turīya-Yantra* (quadrant) for taking observations. The precession of the equinoxes appears to be first mentioned by Viṣṇuchandra (A.D. 580). The rate of precession was given by Mañjula (ninth century A.D.) to be about 58 seconds, compared with the present value of about 52 seconds. A few works of no great importance were written after Brahmagupta till we come to Bhāskarācārya (born in A.D. 1114). He has written two books on Astronomy. Bhāskarācārya has adopted the data of Brahmagupta in respect of mean positions of the sun and the planets. He says in the *Golādhyāya* section of the *siddhānta-śiromaṇi* that the earth attracts by its power any solid body in the sky. May be he had an inkling of the force of gravitation of the earth. Brahmagupta and Bhāskarācārya gave the diameter of the earth as 7,905 miles, the earth-moon distance they then calculated is fairly accurate, but the calculated distances of the planets and the sun are wrong. The next astronomer of repute was Gaṇeśa Daivādhya (born in A.D. 1498). He gives methods for calculating the mean positions of the sun, the moon and the planets in terms of their positions on the 19th March, 1520. The positions of the celestial bodies as described by him on that day are remarkably accurate. His quick methods of calculation are used even to this day. Unfortunately there was no astronomer of distinction after Gaṇeśa and it was during this period that considerable progress was made in Europe in astronomy.

The progress of astronomy in Europe was due to navigation, whereas in India it was due to the religious edicts prescribing that the performance of sacrifices and other religious functions is permissable only at certain auspicious times. Such an attitude probably served as a damper for progress beyond the ability to predict these times.

Discussion. Vedic chronology was the main topic discussed. Dr. R. C. Majumdar objected to the dates given to the Vedic period. Dr. A. S. Altekar did not agree with the astronomical method used in fixing dates. He said that an astronomical fact in a particular work could be based on an observation made a thousand years before the work was written. So the date derived on the basis of that astronomical fact may not necessarily be the date of composition of that work. Dr. A. N. Singh was not in favour of totally rejecting all astronomical evidence regarding the date of a book. In his reply, Dr. Dixit made a distinction between exact and vague descriptions of astronomical events. He suggested that

in the case of an event like the rising of pleiades due East, the time of a text recording it would not be far removed from the time of actual occurrence of the event.

DR. D. N. WADIA. *Geological knowledge in ancient and mediaeval Asia.*

Dr. Wadia referred to Charles Lyell who had quoted passages from ancient Hindu and Arabic writings to show that they possessed some knowledge of the imperceptibly slow changes which the earth passes through over a long period of time. Mohd. Qazwani (c. A.D. 1250) was quoted for an allegory based on the same knowledge.

Dr. Wadia then proceeded to discuss the knowledge of minerals in ancient India. The excavations at Harappa and Mohenjo-Daro (civilisation dated 3500–500 B.C.) give evidence of mining ores from comparatively great depths, the art of smelting metals from ores, the use of copper, silver, and gold and to a lesser extent of lead, zinc and tin and knowledge about metallic alloys.

Ancient Hindu books such as the *Rasaratnasamuccaya* give the metallurgy of calamine and the production of metal from zinc ore. They also describe the localities where metal ores are to be found. Vāgbhaṭa mentions ores of mercury and their application in ancient chemistry and medicine. Sulphur obtained from sulphide ores or probably from 'Barren' island was used for making gun-powder. The *Rāmāyaṇa* and the *Mahābhārata* frequently mention gems and show a knowledge of their properties. Dr. Munn has described mining for gold by the ancient Indians in the Hyderabad area up to depths of 700 ft.

In the Discussion that followed, questions were asked regarding the various minerals and their sources.

DR. A. N. SINGH. *Chronology of Hindu achievements in Mathematics.*

Among the earliest Hindu works on Mathematics are the three recensions of the Vedāṅga Jyotiṣa (1000 B.C.). Then there are the *Śulba-sūtras*, which were written in the period 800 B.C. to 400 B.C. These works give methods of construction of sacrificial altars and an account of the more important geometrical propositions involved in their construction.

The period 400 B.C. to A.D. 500 represents a gap in Sanskrit mathematical and astronomical literature. The names of the mathematicians belonging to that period as well as quotations from their works are available, but the works themselves are now lost, probaby because of a change in style introduced by Āryabhaṭa I. His *Āryabhāṭīya* is divided into three sections: (*a*) *Gaṇita* (Mathematics), (*b*) *Kālakriya* (calculations with time) and (*c*) *Gola* (spherics).

In the 6th century we find Varāhamihira writing his well-known work *Pañca-siddhānta* which contains summaries of the *Pauliśa-siddhānta*, the *Romaka-siddhānta*, the *Vaśiṣṭha-siddhānta*, the *Sūrya-siddhānta* and the *Pitāmaha-siddhānta*, mentioned probably in ascending order of antiquity. Many of the *siddhāntas* were re-written in the new style, i.e. using the place value of new system of numeration, in the sixth century.

In the seventh century may be mentioned Brahmagupta, Bhāskara I and Lalla. The last two were followers of Āryabhaṭa. Brahmagupta has adversely criticized Āryabhaṭa in his *siddhānta*.

Śridharācārya made important discoveries in algebra. He was followed by Mahāvīrācārya who wrote a comprehensive work entitled the *Gaṇitasārasaṁgraha* (A.D. 850). Commentaries and manuals were written by Sumiti Ācārya, Padmanābha, Haridaṭa, Govinda and Śaṅkaranārāyaṇa. Among the prominent writers in the tenth century may be mentioned Mañjula (A.D. 932) and Āryabhaṭa II (A.D. 950). The most prominent writer of the eleventh century was Śrīpati who

wrote the *Siddhānta-śekhara* and *Gaṇita-tilaka*. A large number of *karaṇa* works were also written in this century.

In the twelfth century flourished Bhāskara II (A.D. 1150), one of the outstanding mathematical personalities of India. He wrote the *Siddhānta-śiromani*, a comprehensive treatise on mathematics and astronomy. This work was in three parts. The first part deals with Astronomy, the second, known as *Līlāvati*, deals with Arithmetic and Mensuration and the third part, called the *Bījagaṇita* deals with Algebra. The presentation and literary style of this work are superior to those of any other on the subject.

Nothing of importance written in the thirteenth century is available. Amongst the prominent writers of the fourteenth century may be mentioned Nārāyana, Mahendra Sūri and Makaranda.

The sixteenth century marks another period of mathematical activity in India. Amongst the important writers may be mentioned Nīlakaṇṭha, Jñānarāja, and Gaṇeśa. In the seventeenth century Munīśvara wrote works on Astronomy which sought to affect improvement on the system taught by Bhāskara II.

The eighteenth century marks the end of important astronomical and mathematical activity in India. Interest in mathematics and astronomy was created by the erection of a number of observatories by Raja Jai Singh, and the establishment of a School of Medicine and Astronomy at Jaipur. The most celebrated writer of this School was Jagannātha.

Dr. Singh then proceeded to give the following discussion of the salient features of this historical account: (*a*) Decimal place value notation was invented by Hindus Use of a symbol for zero is found in Piṅgala's *Chandah-sūtra* (200 B.C.). All works after A.D. 500 contained this system. The invention may have occurred about 500 B.C. (*b*) The works written after A.D. 500 contain not only the place value system of notation but also methods of performing addition, subtraction, multiplication, division, root extraction and deal with problems of fractions, proportions and interest. Thus Arithmetic had been developed before A.D. 500. (*c*) The main characteristics of Hindu Algebra examplified by Āryabhaṭa I, Bhāskara I and Brahmagupta are: (i) use of letters of the alphabet for unknowns, (ii) multiplication and division of positive and negative quantities, (iii) use of powers and exponents, and (iv) use of equations. Āryabhaṭa knew the solution of simple and quadratic equations. He also knew solutions of indeterminate equations of first degree. Brahmagupta extended this to the second degree. (*d*) The interest of Hindus in geometry has always been practical. Rules for determination of areas and volumes are found in their works. Greek Geometry was transmitted to them, but they developed it along independent lines. (*e*) Their great interest in Astronomy was responsible for their special study of trigonometry, of series, and of methods of the calculus. They worked with half chords instead of the chords of the Greeks. They defined sine and cosine functions and prepared the first tables of these. They found out the addition formula and used other trigonometrical identities in their calculations. All this is contained in the work of Āryabhaṭa I. In A.D. 932 Mañjula used the following interpolation formula:

$$\text{Sin}\,(\theta + \delta\theta) - \text{Sin}\,\theta = \delta\theta\,\text{Cos}\,\theta.$$

Bhāskara defined the velocity as a differential 'coefficient' and found that the differential coefficient vanished at a maximum or a minimum. The mathematicians of South India continued progress up to the sixteenth century. For example, Nīlakaṇṭha used the following formula:

$$\text{Sin}\,(\theta + \delta\theta) = \text{Sin}\,\theta + \delta\theta\,\text{Cos}\,\theta - \frac{(\delta\theta)^2}{2}\,\text{Sin}\,\theta.$$

They also succeeded in getting infinite series for $\sin\theta$, $\cos\theta$ and $\tan^{-1}\theta$.

Section II. Chemistry, Mineralogy, Pharmacy and Biology

Chairman .. Dr. S. L. Hora.
Rapporteur .. Dr. G. P. Majumdar.

Dr. S. L. Hora. *Zoological knowledge with special reference to fish and fisheries in India before 225 B.C.*

Dr. Hora expressed difference from the opinion held in some quarters that the Hindus and the Chinese contributed very little to progress in Biology. He proceeded to give the following instances of activity in this field among the Indians, at very early times. The classification of animals was on the basis of those having a back-bone and those without it. Other methods of sub-classification were according to the number of feet; differences in habitats, or the number of senses possessed by different types of animals.

Śuśrutasaṁhitā (A.D. 200 to 500; Śuśruta himself lived in 600 B.C.) contains a remarkably modern conception of the correlation between form and locomotion of fishes. If all the Sanskrit synonyms of fish are taken together, one gets a very good definition of fish as a class of animals. In Kauṭilya's *Arthaśāstra* (*c.* 300 B.C.), hints of a very advanced fishery administration are given and metaphors showing knowledge of the habits of fishes are included. Aśoka's Pillar Edict V (246 B.C.) contains five names of fishes which are very significant in regard to their respective characteristic features. On this pillar edict, fish are declared to be inviolable on certain days in the three *chāturmāsīs*. If the 'three *chāturmāsīs*' could be interpreted as the 'third chāturmāsī', then the edict would appear to be meant for the protection of fishes during the breeding season.

The author, in conclusion, directed attention to the great wealth of historical knowledge that exists in ancient Sanskrit literature.

Discussion. Dr. Altekar objected to the interpretation that Aśoka's pillar edict was intended to protect fish during the breeding season. He pointed out that the edict prohibited the slaughter of other animals also during the three days of the three Chāturmāsīs. Dr. R. C. Majumdar advocated caution in claiming scientific knowledge for our ancestors on the basis of insufficient evidence of systematic thought. Dr. Satyanarayanamurti suggested that as the contributions in question were made about twenty centuries ago, they should be assessed against the background of the then existing thought and culture. Dr. Hora gave a suitable reply to these comments.

Prof. P. Ray. *The History of Chemistry in India.*

Prof. Ray traced the origin of chemical knowledge in India to the days of the Mohenjo Daro (Indus Valley) Civilisation (4000–3000 B.C.). An account was given of the various practical arts like the extraction and working of metals, making of glazed polychrome and painted potteries, faience, terra-cotta objects, and the construction of houses with kiln-fired and baked bricks, as revealed in the excavations at Mohenjo Daro and Harappa. Uses of metals like gold, silver, copper, lead and tin, as well as alloys of gold and silver (electrum) copper and tin (bronze), and of copper and arsenic, were referred to. Mention was made of the findings of a large number of ores and minerals used for ornamental purposes. Some like galena, cerussite and cinnabar were believed to have been used as cosmetics and medicine. White lead, gypsum and lime, found in the excavation, were supposed to have been used for plastering work and for the making of floors and drains.

The picture of cosmogenesis, as found in the *Sāṁkhya*, *Yoga* and the *Vedānta* systems of philosophy, and particularly the atomic and molecular theory of Kanāda (*c.* 500 B.C.) was referred to briefly.

The development of chemistry in ancient and mediaeval India, following the Vedic age, was divided on the basis of P. C. Ray's *History of Hindu Chemistry*, into four periods: viz., Āyurvedic period (from the pre-Buddhistic era to about A.D. 800), Transition period (A.D. 800–1100), Tantric period (A.D. 800–1300) and Iatrochemical period (A.D. 1300–1500).

Dealing with the Āyurvedic period reference was made to the two important treatises; *Caraka* and *Suśruta saṁhitās*, which constitute a rational and methodical presentation of the Hindu system of medicine and surgery respectively, and contain almost all the chemical informations of the time. Metals like gold, silver, copper, iron, lead, tin and mercury and alloys like brass and bronze were known in this period. Reference was also made to the *Arthaśāstra* of Kauṭilya (*c.* fourth century B.C.), which described working of metals, making of alloys and coins, as well as varieties of precious stones and gems. An account was also given of the archaeological specimens of copper and iron of historical significance, in the shapes of statues, pillars, caskets, beams, weapons and implements found at different places, testifying to the skill and ability of the workers of metals in Ancient India. Particular mention was made of the iron pillar at Delhi (*c.* fourth century A.D.), iron beams in the temple of Bhubaneswar (*c.* A.D. 540) and that of the Sun-god at Konarak (*c.* A.D. 900–1000) as well as of the solid copper bolt in the Rampura Aśoka pillar (*c.* third century B.C.).

Discussing the progress of chemistry in the transitional period, reference was made to the preparation of metallic compounds like sulphides of copper, mercury and silver.

The Tantric period was described as the alchemical age of Indian chemistry, as it was devoted to the study of the chemistry of mercury (*rasa*) which constituted the main ingredient of the so-called *vital elixir of life*. Much attention was also paid during this period to the preparation of recipes for transmuting base metals into gold. The most renowned Indian alchemist, Nāgārjuna, flourished during this period (*c.* A.D. 700). He was the author of the alchemical treatise, *Rasaratnākara*, as well as of a treatise on metallurgy. Description of various apparatuses for sublimation, distillation, extraction, etc., are found in the alchemical treatises of this period. Red sulphide of mercury (*makaradhvaja*) and the black sulphide (*kajjali*), valued as important medicines, are described in these treatises. It was stated that in the Iatrochemical period, the vast mass of chemical information of the previous periods found their application in medicine. The *Rasaratnasamuccaya* is a very notable treatise of this age.

Attention was drawn to the preparation of caustic alkalies and alkaline carbonates, as described by Suśruta.

Reference was also made to the exchange of scientific ideas between India and Arabia following the Mohammedan invasion, as well as between India and China during the Buddhistic period.

The paper concluded with a discussion of the influence of science on the Indian society, both past and present.

Discussion. Dr. Altekar suggested that in the references cited, full details be given regarding the location of particular statements. He expressed the view that the *Nyāya* and *Vaiśeṣika* systems of philosophy, in their views on atoms were not drawing on observation and experimentation. Dr. Satyanarayanamurti advocated patient research on the cultural relations between the Indus Valley civilisation and the Indo-Aryans of the Vedas. He was also against imputing present-day advanced theories to the ancient Indians when the statements are only intuitive speculations. However, he agreed with Prof. Ray that the *Nyāya* and the *Vaiśeṣika* systems, laid down the methodology of science as being based on experimentation. Dr. Ranganathan suggested that in papers on special subjects, attention should be concentrated on topics closely related to that subject.

In reply to Dr. Altekar, Prof. Ray pointed out that references to the sources of information contained in his paper are given in the bibliography added; the detailed references to every statement made was not possible for consideration of space. In reply to Dr. Satyanarayanmurti, Prof. Ray stated that the theories advanced by the ancient Indians were certainly speculative and were not based on experimental observations. But he only tried to show that the ancient Indians were capable of such conceptions. To Dr. Ranganathan's suggestion, Prof. Ray replied that the theory of cosmogenesis and the atomic theory are certainly an essential part of Chemisty, for Chemistry deals with the sum total of knowledge about matter and its transformations.

PROF. G. P. MAJUMDAR. *The History of sciences in India from pre-Vedic times to eighteenth century A.D.*

It dealt with the sciences of Botany, Medicine, Agriculture and Arbori-Horticulture. Prof. Majumdar discussed the development of Botany as follows:—

The Indus Valley people used to live in villages, cities and towns, wore clothes, cultivated crops, including wheat, barley, millet, dates, vegetables, melon and other fruits and cotton; worshipped trees, glazed their pottery with the juice of a plant and painted them with a large number of plant designs. Thus beginnings in Botany had been made.

Agriculture became a holy and dignified occupation in Vedic India. In Vedic literature we find a large number of terms used in the description of plants and plant parts (both external features and internal structure), a definite attempt at classification of plants, and evidence that manuring and rotation of crops were practised for the improvement of the fertility of soil and the nourishment of plants. There is indication in the hymns of the Ṛgveda that the Vedic Indians had some knowledge of the rôle of light in the manufacture of food in green plants.

During the centuries that followed, the study of Botany made great progress in connection with the studies of the allied sciences, particularly the science of Medicine. In the Caraka Saṁhitā (Sūtra 1, 51-52) it is expressly stated that a man well acquainted with the names and external features of plants, and able to use them properly according to their properties, is to be called an expert physician. The *Vṛkṣāyurveda*, a treatise on Botany by Parasara (c. 250–100 B.C.) gives an account of the life of a plant in its various aspects, including the genesis of the science. Its outstanding contribution is an attempt made by the author at explaining the 'origin of the first organic body (*ādibījam*)'.

Regarding the science of Medicine, Prof. Majumdar stated that some of the outstanding achievements in this field were the knowledge of the circulation of blood; knowledge of pathogenic microbes; development of surgical requisites, anaesthetics and magnifying apparatus, and establishment of hospitals.

As regards Agriculture, Prof. Majumdar stated that its development during the fourth century B.C. reached a high state of perfection. Agriculture became an important department of the State. Meteorological observations were conducted in connection with agriculture. Rain gauge was used to measure rainfall in a region. Pre-sowing treatment of seeds for successful germination and yield was recommended and practised. Use of bone-dust and blood of animals as manure, was also recommended.

Proceeding to the science of Arbori-Horticulture, Prof. Majumdar stated that it played an important part in later days in public administration. Public parks and pleasure gardens were provided by the Government for the health and recreation of the public (Kauṭilya's *Arthaśāstra*). An idea of the subject matter of the science may be had from the subject matter of the *Upavana-vinoda*. This includes: selection of soil, classification of plants, sowing of seeds and various methods of plant propagation, the process of planting, watering plants, rules for the protection

of plants, construction of a garden house, examination of soils where wells are to be dug, recipes for nourishment of plants, treatment of plants in diseases and health and Botanical marvels, (experimental results).*

Discussion. The authorship, genuineness and date of the manuscript of the *Vṛkṣāyurveda* by Parāśara, were subjects of scrutiny. Dr. P. C. Bagchi, Dr. R. C. Majumdar, Dr. A. S. Altekar and others took part in the discussion. The opinion expressed was that the manuscript of the *Vṛkṣāyurveda* should be copied and sent to Sanskritists and Indologists for their opinion as to its genuineness and date, and that if it is found genuine, it should be published. Dr. Varma informed the meeting that he had also procured a copy from Nepal, of a Sanskrit manuscript dealing with fruits and fruit culture.

DR. N. R. DHAR. *India's contribution to the chemical knowledge.*

At about the time that Greek philosophers like Democritus were speculating regarding the ultimate particles that constitute matter, Hindu philosophers like Kanāda were also speculating along similar lines. As regards techniques, the following may be mentioned: metallurgy of iron was well advanced, as evidenced by the Iron pillar at Delhi (*c.* A.D. 500). The technique of preparing steel blades in Damascus, had its origin in India. Preparation, storing and use of caustic alkalies was known, as evidenced by their description in the *Suśruta saṁhitā*. The use of metallic compounds, especially those of mercury, was introduced in Hindu medicine by Nāgārjuna (*c.* seventh century A.D.). Paracelsus probably had been influenced by the East in his use of metallic preparations in medicine. The metallurgy of zinc is described in detail in later books, the *Rasaratnasamuccaya* and the *Rasārṇava* (*c.* A.D. 1200). The latter also described the colouration of flames when metals and their compounds were introduced in them.

Activity in the field of the Physical Sciences was greatest around A.D. 700 to 800. It had almost died out by the thirteenth century for political, social and economic reasons.

SECTION III. APPLIED SCIENCE, TECHNOLOGY AND ENGINEERING

Chairman .. Mr. P. Rochanapurananda.
Rapporteur .. Mr. A. Rahman.

MR. P. ROCHANAPURANANDA. *The history of technical achievements in Thailand.*

The Thai is a practical race. Its achievements are in the way of producing articles to fit its needs. Facts with scientific value have not been recorded by the historians. However, one can indirectly get a glimpse of the achievements of this race.

If we examine the structure of some Thai words, we may see evidence of an attempt at scientific classification. For example names of many plants and animals are compounded from a family name, to which are added other words describing the characteristic appearance of the particular plant or animal.

The ancient Thai was well versed in Agricultural science, as shown by his conversion into fertile soil of the originally swampy ground of the watersheds of the Chao Phya river and its tributaries. At present the Northern Thai have shown themselves capable of irrigating over the hill-sides far above the level of the streams.

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* The full paper has been submitted for publication in the *Archives Internationales d' Historie des Sciences. Belgique.*

In Sukhotai period (A.D. 1257–1350) the art of bronze casting reached its zenith. Another characteristic achievement of that period was the manufacture of Sungkalok pottery. Technical help in the art of making pottery is likely to have been obtained from China around the year 1300, although the Thai had also mastered the art already. The Thai knew also the technique of making fire-arms. After the year A.D. 1511 iron began to replace bronze for cannons, as a result probably of associations with the Portuguese. These iron cannons were very well made and were adorned with designs in silver.

The techniques of making paper, of brewing and making vinegar were also well known. They knew how to calcine limestones and how to use lime mortar in building. Some manuscripts have been found dealing with topics in medicine and alchemy.

Whether European science had dominated the thoughts of those who had written these manuscripts is still a matter of doubt.

Thus the achievements of the Thai are mostly in the field of arts and crafts.

Discussion. Dr. R. C. Majumdar mentioned that the contribution to science of the original inhabitants of Thailand had not been described. Dr. P. C. Bagchi remarked in this context that early history of Thailand had yet to be investigated. Dr. S. R. Ranganathan suggested that a study of the known immediate past may be a helpful guide for the earlier period. Dr. A. N. Singh mentioned that the first copy of an Indian calendar was discovered at Bangkok. Dr. S. L. Hora disagreed with the statement that scientific knowledge originated especially in Europe and the near East. Mr. A. Rahman suggested that Thailand may have possibly been the ground for cultural contact of China, India and the Middle East. The Chairman in his closing remarks mentioned the cultural strength of his country and said that the conquerors always adopted the native culture. He also mentioned that he would try to appeal to the historians and scientists of his country to make further investigations on the History of Sciences in Thailand.

Section IV. Medicine

Chairman .. Dr. A. C. Ukil.
Rapporteur .. Dr. G. V. Satyanarayanamurti.

Dr. G. V. Satyanarayanamurti. *A historical and chronological survey of the practice of hygiene and medicine in India from antiquity.*

Dr. Murti first gave a brief review of the civilisations of the world and their contacts with one another in the field of medicine. These were illustrated by a chart.

Dr. Murti then proceeded to give the following discussion of the progress of medicine in India from prehistoric times. He said that the Vedas give the first indication of the *Tridosha* theory of disease on which the whole of the *Āyurveda* or the ancient Indian medicine, was subsequently based.

When more knowledge accumulated in respect of disease it was added on to the *Vedas* as an appendix or *Upaveda* and constituted the *Āyurveda* which literally means knowledge pertaining to life.

In India originally, that is prior to 700 B.C., the number of humors was restricted to three and the fourth one, blood, was added later in the works of Caraka and Suśruta. The names of Caraka and Suśruta are mentioned as the earliest eminent men in the fields of medicine and surgery. However, the texts of Caraka and Suśruta have been revised, commented upon and enlarged by numerous authors. This has given rise to considerable confusion in respect of the chronology of Caraka and Suśruta. Though their texts reveal a definite knowledge of surgery

in general, the art of surgery was not practised with the same vigour as medicine, probably due to the religious feelings against dissection. Ātreya, who was the brightest pupil of Caraka, established a school of thought based on the teachings of Caraka. By 600 B.C. there were schools of medicine at Takṣaśilā and Kāśi (Banaras), which were imparting organized instructions to pupils in the art of medicine and surgery.

The records that were left by Alexander's followers, and those of Greek chroniclers of subsequent date at the court of Emperor Aśoka, give an account of the knowledge of medicine in India, at the time of Alexander's invasion. Alexander was struck by the skill of Hindu physicians and surgeons whose services were available in the battlefield. Following Alexander's invasion there were intellectual and cultural contacts between Greece and India. The ancient Indians sought knowledge without prejudice

The inscriptions and stone edicts left by Aśoka the Great reveal that there were hospitals for both men and animals in his time. There are books devoted entirely to animal diseases. Aśoka sent Buddhist monks to the length and breadth of the Empire and the courts of the surrounding countries. Thus knowledge from India spread to other countries also.

In the seventh century A.D., two authors, Vāgbhaṭa and Mādhava, made valuable contributions to the *Āyurveda* literature. Vāgbhaṭa's *Aṣṭāṅga-saṁgraha* is a book on the eight aspects of medical treatment which were long in vogue in Hindu medicine. Mādhava's *Vidāna* is a book on diagnosis.

About the year A.D. 715, Harun and Mansur, two Arab scholars, came in contact with Indian thought. The Arab texts indicate an influence of Hindu medical literature The Arabs assimilated the Greek and Roman thought as well. Their knowledge was later transferred to Europe.

It appears that from the eleventh to the fourteenth century A.D. there were a number of commentators on Hindu medicine. Towards the end of this period Sarangadhara produced a pharmacopaeia. In this, the use of metal compounds in the cure of disease was stated for the first time in the world's medical literature. A treatise on medicine was published by Bhāvaprakāśa in about A.D. 1550. Subsequent to this date, it appears that there have been no outstanding contributions to Indian medical literature.

Dr. Murti then gave a chronological review of Āyurvedic literature with the help of a chart. This review shows that there is a sense of continuity in these texts and the whole practice of medicine was based on the Tridosha theory of health and disease, which remained unaltered through the centuries.

Next, Dr. Murti explained the Tridosha theory. On the basis of this theory an equilibrium of the three fundamental principles, *Vāyu*, *Pitha* and *Kapha*, is necessary for the maintenance of health. A practitioner of Āyurveda comprehends health and disease on the basis of Doṣas (Principles), Dhatus (body constituents) and Malas (waste products). It is held that food, drugs and external application of drugs influence the body by their physical qualities, chemical constitution, and physiological actions. These last are held to be dependent on the natural constitution, or Prabhava, of the individual. The aim is to rectify the disturbed Doṣa and hence the Dhātus and Malas.

Dr. Murti then reviewed the extent of medical and surgical knowledge in the ancient Indian text-books in its important aspects. These were :—

(*a*) Nothing but the highest ideals were enjoined on those practising the art of medicine (C.S. IX, 6). The text of Caraka abounds in reference to personal hygiene.

(*b*) Chapter 9 of Suśruta mentions how a student of surgery should practise incision, excision, scraping, probing, tying, suturing, venesection and cauterisation on vegetables, skins of animals and dead animals.

(*c*) Because the physician is unable to name the disease he should not desist from treatment. Thus Indians adopted symptomatic treatment quite early. (C.S. XVIII, 51 54).

(*d*) Chapter XVII of Suśruta describes suppurating and non-suppurating swellings and a competent surgeon is enjoined to differentiate them. The method of extraction of arrows and splinters is given ; also the operation of piercing the lobules of ears which is necessary for the wearing of Indian jewellery is described. Chapter XXV describes the fundamental surgical procedures such as incision, excision, scarification, aspiration, extraction of foreign bodies, evacuation by incision and suturing of open wounds.

(*e*) Fractures were treated with the use of splints while dislocations were reduced with accuracy and skill. Depletion of blood (by leeches and venesection), induction of vomiting, sweating and purgation, and enemata were commonly used as methods of treatment. Couching for cataract, laparotomy, herniotomy and tonsillectomy were practised. Rhinoplasty was practised as late as 1794.

(*f*) The value of exercise was early recognised but it was recommended that it should not be indulged to excess (C.S. VII, 31).

(*g*) There is great emphasis on diagnosis, description of diseases, and prognosis, while operative and medical procedures are described vividly.

(*h*) Though knowledge of anatomy is meagre, there is some theoretical attempt at the physiology of health and pathology of disease.

(*k*) The ideals of the nursing profession are stated definitely (C.S. IX, 8).

(*l*) There is also reference to the construction, equipping and staffing of a hospital (C.S. XV, 6).

Discussion. Dr. Hasan, Mr. Rahman and Dr. Ukil desired that reference should have been made to the social factors that contributed to the development of *Āyurveda* and its later decline. The author stated that it was an aspect that must form the subject of a separate paper. Prof. P. C. Bagchi and Prof. Altekar were of opinion that the quotation from the Ṛgveda should not be accepted to convey the Tridosha theory of later *Āyurveda*. Dr. Bagchi said that there was abundant evidence of the existence of Tridosha theory as well as several references to medicinal plants and diseases in the *Śatapatha Brāhmaṇa* which dates back to 800 B.C. The author was prepared to take the stand for the earliest reference to *Āyurveda* on this last statement. Prof. R. C. Majumdar objected to giving precedence to Caraka over Ātreya and to ascribing to him a date earlier than the sixth century B.C. He considered the second century B.C. as more appropriate and deemed that Ātreya of the sixth century B.C. had nothing to do with Caraka. He also suggested caution in accepting Ceylonese records in respect of reference to hospitals. Dr. N. P. Chakravarti advised the inclusion of the Bower manuscript in the list of literature of Indian medicine.

Dr. A. C. Ukil. *The history of Indian medicine from ancient times to the eighteenth century.*

In the *Rg-Veda*, the earliest mention of medicinal plants is found. The *Atharvaveda* has sections dealing at length with medicine, surgery and hygiene. Following this period, the *Āyurveda*, or the science of life, was written, which is regarded as a branch of the *Atharvaveda*,

Through several centuries scholars like Dakṣa, Indra, Bhāradwaja, Bhṛgu, Dhanvantari and Ātreya developed the *Āyurveda*. Agniveśa, a pupil of Ātreya,

wrote the *Agniveśasaṁhitā*. Other treatises followed which dealt with the diseases of animals also.

After a period of decadence, there came Jīvaka, physician to King Bimbisāra, a contemporary of the Buddha. He specialized in children's diseases and wrote an elaborate treatise called *Kāśyapa Saṁhitā*.

The *Arthaśāstra* of Kauṭilya, a minister of Chandragupta I, gives a good description of the development of the science of medicine, botany and forestry. It mentions rules for the practice of medicine, measures for the control of epidemics, and regulations on hygiene and free hospitals.

The edicts of Aśoka reveal a vast amount of organization for the relief of human and animal suffering. It comprised cultivation of medicinal plants, provision of hospitals and organization of a sanitary department.

Suśrūta, a pupil of Dhanvantari, wrote a treatise on surgery, the *Suśrutasaṁhitā*. It suffered from many interpolations, until Nāgārjuna, the great chemist, redacted the whole book. Nāgārjuna was responsible for the introduction of metallic preparations, principally those of mercury, sulphur and iron.

Caraka, the court physician of Kaniṣka (first century A.D.) redacted and re-edited two-thirds of the *Agniveśasaṁhita*, while the remaining one-third was later on redacted by Dṛidhabala (fourth century A.D.). This redacted treatise is known as the *Carakasaṁhitā*. In it 2,000 vegetable remedies have been described, besides a few mineral and animal drugs.

About the fifth or sixth century A.D., Vāgbhaṭa collected materials from the then available Āyurvedic literature and compiled two texts called the *Aṣhṭāṅgasaṁgraha* and the *Aṣhṭāṅgahṛdaya Saṁhitā*. Captain Bower discovered in 1870 some manuscripts dealing with medicine, written by a Buddhist (presumably derived from the Hindu works of this period).

Near the end of the eighth century A.D., the essentials of Hindu medicine were translated into Arabic. By holding Medical Congresses of Hindu, Greek, Egyptian and Arab medical scholars, the system of Arab medicine was developed.

In the period A.D. 600–A.D. 1200, progress was not spectacular; however, many books were compiled. Among the better-known authors of this period were, Mādhava Kara (seventh century A.D.), Sorhala (eighth century), Vrinda (ninth century), Chakrapāṇi (1060), Vāṅgasena (eleventh and twelfth centuries), Gayedāsa (eleventh century) and Nityanātha (twelfth century).

Then followed a period in which the chemists devoted considerable attention to the production of medicines. The *Rasaratnākara*, the *Rasaratnasamuccaya* and the *Rasaratnamāla* are some of the books dealing with the advances thus made.

With the advent of Muslim conquerors, the Arabic system of treatment became the state system of relief and the Āyurvedic system was pushed to the background.

By the time the foundations of the Indian Empire were laid by the British in 1757, the indigenous systems of medicine had further degenerated; the first Medical school on the Western system was established in India in 1822.

The paper has a bibliography which includes 37 authors.

Discussion. Dr. P. C. Bagchi considered that there was no period of decadence and that Chandragupta I belonged to the second century A.D. Prof. R. C. Majumdar was of the opinion that there was a certain amount of confirmation in respect of the various periods referred to by Dr. Ukil. Prof. Altekar desired that Dr. Ukil should have given references to the original texts in the Vedas. Col. P. C. Datta wanted to know if there was any indication of the type of medicine used by the people of the Indus Valley civilization.

DR. S. K. CHATTERJI. *Legal medicine, its study and practice in India (from a historical point of view).*

'Legal Medicine' is a branch of medicine which deals with the application of medical knowledge to the purpose of the law and 'Toxicology' forms a branch of the study of Legal Medicine.

The subject of Toxicology, has been dealt with in the *Atharvaveda* under the heading *Agada Tantram* and in the *Suśrutasaṁhitā* under the heading *Kalpasthānam*, and though codes of law regulating the medical profession are to be found in the Vedas and the Codes of Manu, the first systematic study of the subject of Legal Medicine was actually started in the Western countries.

SECTION V. GENERAL PROBLEMS, METHODS AND PHILOSOPHY OF SCIENCE

Chairman .. Dr. R. C. Majumdar.
Rapporteur .. Dr. A. S. Altekar.

MR. A. RAHMAN. *Social factors in the history of sciences in India.*

The main thesis of the paper was that techniques of an epoch determine the philosophic ideas and intellectual atmosphere. The paper explained the point by taking Indian examples. It divided Indian history into three main periods as follows :—

(1) Archaeological, i.e. Mohenjo-Daro period : No written records of this period are available. However, from the archaeological data, one gets a picture of India, which resembles that of other civilizations of those times. In fact the first technical revolution had taken place in history round about 4000 B.C., and by roughly 3000 B.C., it was completed. It involved the use and control of fire, control of flooding and irrigation and technique of agriculture, domestication of animals, smelting and use of metals, invention of the plough and the wheel, potter's wheel, wheeled carts and probably the spinning wheel. The basic factor underlying these discoveries was the division of labour in society. A vital question arises, as to why the existing techniques did not develop further. Possible causes are the following : (*a*) division between technicians and scribes, (*b*) political suppression of inventions. There is need for research to find out the real causes.

(2) The period 600 B.C. to A.D. 600. This period is characterized by religious reform movements, such as Buddhism and Jainism. We do not have much documentary data on the technical developments. However, monuments such as the Iron pillar at Delhi, speak for the skill and understanding reached in technical processes. There is considerable development of fields of learning, such as astronomy, mathematics, and medicine. In this period, there also existed, materialistic systems of philosophy, such as the Nāstika, Nyāya and Vaiseṣika systems. A noteworthy feature of the Vaiseṣika system was the development of an atomic theory by Kanāda. Barring, some differences in detail, the development in this period also is very similar to that in Greece and other countries. Again the question arises as to what were the socio-economic and political factors that came in the way of further development.

(3) The third period of an outburst of cultural activity starts round about Akbar's time and continues up to the time of the British occupation of the country. But this was the activity of a feudal society as distinct

from a mercantile society. Artisans and peasants had no incentive for increased production as they felt economically secure under the feudal lords. There were probably prejudices against new professions. Cheap labour obviated the need for machinery. All these factors hindered technical progress.

In the eighteenth century interest in Astronomy was revived under the patronage of Raja Jai Singh. The question arises as to whether India, if left to itself, would have developed towards industrialization, or whether the presence of the British was necessary for a technical revolution. A proper appreciation and investigation of such factors will help us to understand Indian history, and it will be a contribution to the history of sciences.

Discussion. Dr. S. L. Hora, Dr. P. Saran and Dr. A. N. Singh put varying degrees of emphasis on the influence of environment and of individuals on the growth of sciences. Dr. N. P. Chakravarti suggested a more careful study of the prehistoric man; and Dr. R. C. Majumdar suggested the same for the Vedic period. Dr. Altekar stated that the use of the scriptures for reconstructing the history of sciences, was justifiable where no other data are available. Dr. Bagchi drew a distinction between Greek and Indian genius, saying that the latter was more metaphysical than practical, and that the Indians were satisfied whenever an invention was just sufficient to meet the need of the hour. Mr. Rahman stated in his reply that we should reconstruct the atmosphere of each age to understand its scientific achievements; and that to discover the cause of progress or stagnation is the most important desideratum for historians of science.

DR. P. C. BAGCHI. *Indian sciences in the Far East.*

Dr. Bagchi tried to prove that the Greeks and the Indians were the only two people which continued to develop scientific knowledge, sometimes in collaboration, after the fall of the ancient civilisations of Egypt and Babylonia. They were also responsible, according to Dr. Bagchi, for the dissemination of scientific knowledge among different peoples. The Greeks transmitted it to the Christian world and later to the Arabs while India transmitted it to Eastern Asiatic countries, Central Asia, China, Tibet, Mongolia, Korea, Japan and the countries of the South-East Asia—Indo-China and Indonesia.

Elements of Indian scientific knowledge first infiltrated to China as early as the third century B.C., most probably through the Scythian intermediaries of Central Asia. In this period the Chinese received Indian geographical knowledge—the conception of a central mountain from which rise four rivers, the theory that the earth consisted of seven continents surrounded by seas and situated around the central mountain, etc. Some elements of astronomical knowledge were also transmitted in this period, such as the knowledge of the 28 lunar mansions, the knowledge of the distinction of planets from the stars, etc. The first calendar was prepared in 104 B.C. but as the knowledge of the precession of the equinoxes was still lacking, the solsticial points were taken as fixed.

Direct contact between India and China was established in the first century B.C. and that led to further development of astronomical knowledge. During the next few centuries greater precision was arrived at in the matter of calculations. In the sixth century, a number of Sanskrit astronomical treatises were translated into Chinese and in the seventh century Indian astronomers were appointed on the official Astronomical Boards.

Knowledge of mathematics also went to China along with astronomy. Mathematical treatises composed in China during the first few centuries of the Christian era seem to have been based on Indian mathematics. The texts are called *Ching Sutra* in the Indian fashion. The unknown quantity in Algebra is called *t'ien-yuan*

'monad' which seems to be a translation of Sanskrit Vija (of Vijaganita). The solution of the indeterminate problems is called pulverisation which is a translation of Sanskrit *kuṭṭikara*. In the sixth century, a number of Sanskrit Mathematical texts were translated into Chinese. China transmitted these elements of scientific knowledge of astronomy and mathematics to Korea and Japan.

Indian medical texts were in use in the kingdoms of Eastern Turkestan during the first few centuries of the Christian era. Some of them were even translated into local languages. The Chinese also borrowed numerous elements of the Indian medical system. Although translations of Sanskrit original texts in Chinese are few, the Chinese medical texts contain a large number of names of Indian drugs and besides the Indian ' theory of wind '.

Indian medical texts were translated into Tibetan after the seventh century and subsequently they were carried to Mongolia where they were translated into Mongolian.

In the Hindu kingdoms of South-East Asia, Indian mathematics, astronomy and medicine were studied in Sanskrit original. What influence they have left in those countries after the disappearance of direct Hindu influence still remains to be discovered.

In the discussion period, Dr. A. N. Singh suggested that translations of the Chinese works showing the influence of India, would enable us to get a clearer picture about the Indian sources. In his view the interpolation of a few Greek words into Hindu Astronomy does not prove the existence of a dominating influence.

DR. A. S. ALTEKAR. *A perioduise and critical survey of India's achievements in the scientific field.*

The data available for reconstructing the history of sciences in ancient India, are rather scanty.

The History of Sciences in India may be divided roughly into four periods, viz. the early Vedic period (c. 2000 B.C. to 1000 B.C.), the later Vedic period (c. 1000 B.C. to 500 B.C.) the Nanda-Gupta period (500 B.C. to A.D. 500), and the Early Mediaeval Period (A.D. 500 to A.D. 1200).

In the early Vedic period, the Indian Aryans were emerging from the pastoral to the agricultural stage. People had an open and enquiring mind and manual labour and arts and crafts were not held as plebian. Practical needs of the society determined the direction and progress of science. The year was taken to be of 12 months or 360 days. An inter-calary month was added to equalise the solar with the lunar year. Some planets were distinguished from stars. The phenomenon of eclipses was noted but its cause was not known. Diseases were attributed to malignant spirits. Charms as well as herbs were used to cure these.

In the later Vedic period, respect for tradition was cleverly harmonized with regard for progress. Astronomy, medicine and practical geometry were developed. The processes of obtaining metal from ores of the gold, silver, copper and iron were well known. Foreign contacts were few.

The Nanda-Gupta period was a creative and fruitful period. There was intellectual contact between the Greek and Indian scholars. However, the borrowing was by no means blind or one-sided. There was remarkable progress in Astronomy, Mathematics and Medicine. The diurnal motion of the earth and the true causes of eclipses were known and the decimal notation was invented. The medicinal system was still mainly herbal but dissection was practised for first hand knowledge of anatomy. There was progress in metallurgy and practical arts. China and South-West Asia came under the influence of India.

Early Mediaeval Period—In the fields of mathematics and Astronomy Varāhamihira, Brahmagupta, Lalla and Bhaskara were the principal authors of this

period. Some of their works were mere manuals; but others record considerable progress in mathematics and astronomy. Brahmagupta discovered the solution of the second degree indeterminate equations. Many previous observations and calculations were corrected. After the rise of Islam, there was contact with the Arab scholars. In the realm of medicine mineral preparations, especially of mercury, were introduced. Huge temples were erected in this age, in Orissa, Bundelkhand and South India, showing considerable knowledge and progress in civil engineering.

Several new developments of this period were detrimental to the progress of science, for example, (i) veneration for old traditions tended to stifle new discoveries, (ii) arts and crafts were regarded as plebian, (iii) the scholars became narrow and bigoted, (iv) royal support no longer remained available for Sanskrit learning after the disappearance of Hindu rule.

The rational outlook on life is now reasserting itself. Progress in science and industry is the first and foremost concern of our modern universities and governments. We may, therefore, look forward to an era of fruitful scientific and industrial progress in the country.

DR. R. C. MAJUMDAR. *Scientific achievements of the ancient Hindus; chronological and sociological background.*

Dr. Majumdar began by emphasizing the need for an understanding of the real connotation of the phrase 'Scientific Achievements'. He stated that we cannot speak of scientific achievement unless we have a clear evidence of systematic thought and careful observation of the phenomena of nature. He gave examples of what he considers as sound and unsound judgments in this connection.

Further he dealt with the difficulties of fixing the dates of the earliest works of literature and science; and tentatively fixed limits for the more important ones. A note of caution was sounded in the case of treatises whose versions now available are revisions of the earliest texts.

Dr. Majumdar then discussed the probable lines of scientific progress in different periods of Indian History on the basis of such sociological and political factors as are fairly well-known to us. The earliest period represented by the civilization on the banks of the Sindhu, and reaching back to the third millennium B.C., contains clear traces indicative of scientific knowledge of a fairly advanced type. The early Vedic age was also conducive to the growth of Science. But then followed a reaction in the later Vedic Age in which all the tendencies were opposed to a critical inquiry into the problems and mysteries of physical nature. The sixth century B.C., which saw the birth of heterodox religious sects like Buddhists and Jains, also ushered in a rational age dominated by a new and critical spirit of inquiry which favoured the growth of sciences such as medicine, astronomy, mathematics, mineralogy, chemistry, etc. These reached their high watermark of development during the Gupta age (A.D. 350-600) which saw a galaxy of scientists headed by Āryabhata. Unfortunately the Gupta age also witnessed a revival of Brahmanical religion which, true to its old orthodox views, positively discouraged all arts and sciences and banned all advanced scientific views which were opposed to the old faith, belief, and conventions. Thus the normal growth of scientific ideas was arrested, and a dark age set in when the Hindus lost their political independence in the thirteenth century A.D.

Discussing foreign contacts, Dr. Majumdar stated the following:—

There can be hardly any doubt that Greek astronomy exerted a great influence on the development of that subject in India, but generally speaking the borrowings seem to have been the other way. The Arabs derived from India a great deal of their knowledge of Mathematics, Astronomy and Medicine, and they spread abroad

the Indian system of decimal notation which has revolutionized the growth of Mathematics, and thereby also science, in general, throughout the world.

Discussion. The papers of Dr. Altekar and Dr. Majumdar were taken up for discussion jointly. Dr. Hasan and Mr. Rahman, pointed out that the rise of the Arab school took place much earlier than the Abbaside period. Dr. Bagchi stated that the *Bṛhatsaṁhitā* is not a unitary work and the whole of it may not be the work of Varāhamihira. He also suggested the use of the works of Arab scholars who resided in India for the purpose of reconstructing history. Dr. Dhar and Dr. P. Saran were of the opinion that a closer study of the causes of decline of learning in India is needed. Dr. Murti stated that the achievements of the ancient Indians should not be dismissed as practical recipes and unverified speculations. In his view the decline was due to lack of political tranquillity and social security. Dr. Hora asked for information from the authors regarding the Sanskrit literature on Zoology and Agriculture.

Dr. Kothari remarked that the historians had been more critical in their approach, than the scientists. He also stated that progress of science in Europe after the Renaissance had been due to 'an open mind in a closed system'. He explained the 'closed system', as being one in which attention is directed towards particular problems as distinct from philosophical issues.

DR. PRIJOHUTOMO. *Indonesian cultural history until the seventeenth century.*

Before Indonesia was inhabited by the present population, the archipelago was occupied by peoples of Negrito and Wedda origin. About 2,500 years ago, these original people were driven away by the Indonesians, who were coming from Asia. These settlers knew navigation and astronomy, and were skilled in growing rice, cattle breeding and the making of iron objects.

The history of Indonesia begins with the contacts with India at about the beginning of the Christian era. Their greatest influence was on Java. Although there were certainly commercial relations between the two countries, yet the more important factor was the flow of Buddhist missionaries from India, and of pilgrims to India. These contacts produced a fine Buddhist art.

Not only Buddhism, but also Hinduism entered Indonesia. The Hindu influence was greatest in respect of culture and the form of Government. In addition to the information obtained from Indian and Chinese sources there have also been found in Indonesia some copper plates and stone tablets which bear witness to this influence. The Hindu influence on architectural art was strong in Central Java. In Eastern Java, the Hindu art was gradually displaced by the original Javanese art. Buildings in West Java have left no remains, as they were made of fast decaying materials. The Eastern Javanese art declined in the fifteenth century. With the arrival of Islam, the Hindu Javanese art continued to be looked upon by the Javanese as the national art. Because the influence of the Dutch started in the 17th century, a new Islamic art did not develop.

The Javanese literature was also influenced successively by the Hindu, Islamic and European cultures. The Hindu epics entered the Javanese literature also, though in a considerably changed form. In the matter of content, style and meter, etc., the Javanese literature followed the Hindu literature, at first. However, it gradually evolved along independent lines. At last in the history of Java, a Hindu-Javanese culture appeared, the kernel being of a Javanese character.

Java, Sumatra and Bali were influenced by the Hindu culture through direct contacts. Other places in Indonesia were influenced in turn by these. Before Islam entered North Sumatra, it had already been much influenced by the Persian and Indian cultures. But from the nineteenth century onwards, religion developed, in an orthodox direction. as the influence of Arabia was felt directly.

From the sixteenth century onwards, European influence began to be felt through missionaries. Since the seventeenth century Indonesia has been influenced principally by the Dutch.

Discussion. Dr. N. P. Chakravarti remarked that in the Indonesian culture, Indian influence had blended harmoniously with the local culture. As an example of this, he cited the fact that some of the Indian heroes were believed by the Indonesian people to be their own heroes.

Discussion on the Teaching of History of Science

Mr. A. Rahman. *The history of sciences and some problems of teaching.*

The paper began with a discussion of how social environment moulds human activity, including science. It continued as follows:—After the Renaissance there was a separation of the 'Humanities' from 'Science'. The reasons were that (*a*) the influence of science was mainly in the material field, (*b*) whereas the 'Humanities' were based on an appeal to antiquity, 'science' was a return to the contemplation of brute facts observed by experimentation, and (*c*) the newly born universities encouraged scholarship, rather than the new methods of discovery.

Our latest experience shows that this separation is undesirable. Science has begun to play a dominant rôle in the activities of humanity. A powerful new tool, namely 'Scientific Research' has been forged Out of scientific activity, ethical problems arise inevitably, the atom bomb being an obvious example. This means that there is a need for general education, no less than for specialized education. This dual need poses a big practical problem for educationists The situation is made more acute by the fact that in the teaching of science also, it has been compartmentalized into various branches.

Teaching of the History of Sciences can bring out the artificiality of the division between science and humanities, and between the various branches of science. It will give an understanding that the growth of science is an evolutionary process, in which many needs, concepts and techniques interact. Again, it will not only bring a new consciousness of the positive factors promoting the growth of science, but also the negative ones retarding it.

Such an understanding is vital for us in India. It will put the old and the new in their proper prospective, and will facilitate the use of the scientific method in solving our problems.

The scientific method has to be applied to education also. The universities have been trying to impart knowledge which the students may be able to *transfer* into use later. They should give them the ability to discover and invent where they meet the ever new problems of life. Owing to historical reasons, teaching in Indian Universities has been particularly narrow, and unrelated to the Indian social background. Teaching of the history of sciences has been neglected, although it has received considerable attention in foreign universities.

The point, however, is not to give a background of science and humanities from mere historical angle but to impress upon the student the historical nature of the process and bring home to him the dominant human tendencies in the various epochs of human history.

The paper was accompanied by a proposed syllabus for teaching of the history of sciences in universities as a combined course for Science and Arts students of Intermediate and Degree classes.

Dr. A. Singh. *A history of sciences course for undergraduates.*

The author presented some practical aspects of a course in the History of Sciences for undergraduates, started at Delhi University, five years ago. The following issues were raised:—

(*a*) Because of the limited background knowledge of the students, the subject matter should be restricted to a comparatively few topics of fundamental importance.

(*b*) It would be advisable to present the subject in two stages. In the first, the growth of sciences as a whole may be presented against the background of the history of mankind; and thus the social relations of science clearly brought out. In the second stage the growth of the various branches of science may be taken up individually, the continuity of ideas being thus emphasized.

(*c*) It is essential that examiners should have a clear idea of the objectives being followed in teaching the subject. This is especially necessary because the subject is so vast and admits of several approaches.

The papers of Mr. Rahman and Dr. Singh were taken up for discussion jointly. At first doubts were expressed regarding the utility of a course on the History of Sciences, under the present conditions. However, towards the end of the discussion, the concensus of opinion was that it would be well to make a beginning in this direction in spite of the existence of handicaps regarding source materials and maturity of students. In order to stimulate the interest of students, extension lectures on sciences should be arranged. The teaching of the History of Sciences may include Sectional Histories but it must also include a general survey in which the various sciences are inter-related, and their interaction with society is brought out.

Other Papers Received

A few papers were received from authors, who could not be present at the Symposium. The following are brief descriptions of the contents of these papers:—

Dr. R. V. Seshaiya.[1] *Ancient Indian ideas of human development.*

This paper draws attention to the *Garbha Upaniṣad* (older than the *Purāṇas*), as a source of information regarding ancient Indian ideas on human development. A translation and discussion of two *mantras* describing the various stages of development of the human embryo, are given.

Mr. N. N. Chatterjee.[2] *Ancient India's contributions to geology and mineralogy.*

In this paper a more or less literal translation is given of the passages in literature, which deal with geological or mineralogical knowledge. The account is divided into the following periods: pre-Aryan period, Vedic period, period of Kauṭilya, period of the epics, period of Purāṇas, period of Caraka and Suśruta, and Kuṣāṇa and Gupta period.

Mr. A. K. Yegnanarayana Aiyer.[3] *Dairying in ancient India.*

The source materials are given as the Saṁhitās of the four Vedas, the later epics and Purāṇas, the Arthaśāstra of Kauṭilya, some Tamil classics and ancient paintings and sculptures. Evidence is given of the veneration in which the cow was held even in Vedic times. The knowledge of the ancient Indians on the following topics is then discussed: dairy cattle, breeds and milk types; the feeding of animals; milk and milk products; and the care of sick cattle.

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[1] Head of the Department of Zoology, Annamalai University, Annamalainagar.
[2] Department of Geology Calcutta University, Calcutta.
[3] Retired Director of Agriculture, Mysore.

DR. (MRS.) BANI CHATTERJI.[1] *Musical science and scientific relations between East and West from the historical point of view.*

The paper discusses the origins of music, characteristics of Eastern and Western music, and the contacts between East and West in this field.

DR. P. M. MEHTA[2] *The medical man and his ideals in the golden age of Āyurveda.*

The paper discusses the aims, dress, behaviour and fees suggested for the medical practitioner, in the Indian medical literature. The ancients' views regarding the Royal Physician, the attendant for a patient, and quacks, are also given.

LT.-COLONEL B. L. RAINA[3] *The study of medical history in India.*

The paper discusses the approach to the study of medical history, the field to be covered, and the avenues still unexplored. It also gives suggestions for research.

MR. J. K. DHOLAKIA[4] *Progress of sciences in South Asia before the eighteenth century.*

This paper is a general survey. It includes many quotations from the source materials.

DR. K. K. DATTA[5] *Impact of the industrial revolution on India's economy.*

The paper discusses how the most important industry of medieval India, namely manufacture of cotton cloth, was gradually stifled by the advent of the Industrial Revolution in Europe. It then describes the changes in India's economy that followed the decline of India's cotton industry. The paper includes an extensive bibliography.

[1] Tagore Bhawan, Jorasanko, Calcutta.
[2] Dean, Ayurveda Medical College, Jamnagar.
[3] A. M. C., New Delhi.
[4] Mining Engineer, Dhansar (Manbhum).
[5] Professor of History, Patna College, Patna.

APPENDIX VIII

RESOLUTIONS

1. The Symposium recommends that National Groups affiliated to the International Union for History of Sciences be founded in each of the participating countries of South Asia.

2. This conference of Indian historians and scientists resolved that a National Group of History of Sciences be formed in India and a Committee consisting of the following be instituted to take necessary steps to bring the Group into existence:

Prof. R. C. Majumdar, Dr. A. S. Altekar, Dr. S. L. Hora, Dr. D. S. Kothari, Dr. A. N. Singh, Dr. R. C. Majumdar, Dr. Amarjit Singh, Prof. Ram Behari and Prof. M. Habib.

3. The Symposium further resolved to institute a Board under the National Institute of Sciences of India for the study of the History of Sciences.

APPENDIX IX

HISTORY OF SCIENCE AND TECHNOLOGY IN INDIA AND SOUTH-EAST ASIA

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The History of the sciences, pure and applied, in India and other parts of South Asia, still remains the greatest 'unknown continent' in this world of study, so important for the general culture history of mankind. It was, therefore, an excellent idea to gather together in November 1950 a group of Indian and South Asian scholars interested in the history of science, and to publish, even if only in a provisional form,[1] the papers which were read to the symposium. The result shows clearly that there is an enormous amount of material already available for the work of synthesis, in which we must attempt to place the development of science and scientific thought in India in its proper framework of parallel developments, some later, some earlier, in Europe and in other parts of Asia. It is also clear, however, from the papers in this symposium, that the task is perhaps the most difficult of all those which face historians of science today, owing to the extreme uncertainties in the dating of the most important texts, and even of actual objects which have survived.

Some of the papers, such as the general surveys given by A. S. Altekar and by R. C. Majumdar, are judicious and careful concerning this, and will no doubt be in greatest demand if copies are available separately. Some of the specialised papers (such as that by B. L. Raina) are also reasonably cautious. Unfortunately, this cannot be said of the majority of the papers, which put forward quite unacceptably early datings especially for texts purporting to date from the first two millennia B.C.; particularly bad examples are the two papers on astronomy (by Shukla and Dixit) as well as others on chemistry (by N. R. Dhar), embryology (R. V. Seshaiya) and medicine (G. V. Satyanarayanamurti). The accompanying table shows the divergence of opinion. It is even maintained that the Babylonians owed the sexagesimal division of the circle and the system of twenty-eight lunar mansions to India. In general, we find throughout the papers too marked a chauvinistic tendency, an effort to minimise foreign influences on Indian science and to emphasise all outward transmissions—this is, of course, all too easy so long as Indian history has not been provided with a strict chronology. Typical of the desire to make a case is the praise bestowed upon the potters of the Mohenjo Daro civilisation (P. Ray), where no comparison is made with other pottery products studied by the author, nor is any ceramics expert cited whose opinion might carry weight. Along with these tendencies goes the fault of trying to read too much into ancient texts, as when the Pillar Edicts of Asoka or the text of the 'Arthaśāstra' are appealed to as evidence for advanced fishery legislation (S. L. Hora); here the writer is roundly taken to task by a colleague (R. C. Majumdar). But great uncertainty seems to reign, for the sceptic himself seems to be perhaps too sceptical regarding the military use of arsenical smokes—which were certainly developed quite early by the Chinese. So while most of the writers are too rash, others are too modest, notably the writer on Siam (P. Rochanapurananda), who disclaims any contribution of his own Thai people to science, failing to mention the work of la Loubere[2] in the seventeenth century, which shows that Europeans were at that

[1] Proceedings of a Symposium on the History of Science and Technology in South Asia, Delhi, Nov. 1950. Organised by U.N.E.S.C.O., and obtainable in mimeographed form from the U.N.E.S.C.O. Field Science Co-operation Office, c/o University of Delhi. About 150 pages, mostly single-spacing, mimeographed foolscap-size typescript.

[2] A New Historical Relation of the Kingdom of Siam.... Tr. A. P. Gent, F.R.S., from the French edition of 1691 (London, 1693).

time much interested in what the Siamese knew. Even if this turned out to be mostly Chinese—as it did—Siam must certainly have had something to show in fields such as textile technology. The same applies to the paper on Indonesian culture (Prijohutomo).

Until the problem of the dating of Indian texts is solved, all those of transmission must remain impossible to deal with. Hence the confidence shown by papers such as that on Indian-Chinese relations (P. C. Bagchi) is entirely misplaced. We cannot admit the derivation of the Chinese lunar mansions from India (probably both systems are ultimately Babylonian). It is absurd to claim Indian influence on a mathematical work such as the 'Sun Tzu Suan Ching' (third century A.D.) on the ground that the word 'Ching' was afterwards used for translating the term 'Sūtra' in Buddhist texts—all canonical books were known as 'Ching' from the time of the Warring States (fourth century B.C.). Nor is there any mention in this paper of the numerous cases which have been noted of the reappearance of Chinese mathematical problems in subsequent Indian texts.

Dating of Indian Text.

	Dating accepted by critical modern scholarship (and in papers by A. S. Altekar and R. C. Majumdar).	Paper by K. R. Dixit and G. V. Satyanarayanamurti.	Paper by K. S. Shukla.	Paper by P. Ray, S. L. Hora and R. V. Seshaiya.
Vedic material	*c.*—14th (—1400/—1000)	6000/—1500	—4000/—2000	..
Upanisads period	—10/—6th	17th/ 7th	..	—2500/—2000
Calendrical Texts:				
'Jyotiṣa Vedāṅga'	—600/ —200/	..	—1400	..
'Sūrya Prajñapati' ..	*c.*—200		—500	..
Astronomical Text:				
'Sūrya Siddhānta' .	+4th or 5th	..	0	
Economical and Technological Text:				
'Arthaśāstra' ..	—1st	..	..	—4th
Medical and Biological texts:				
'Suśruta Saṃhitā' ..	1st (Present text + 11th)	7th		—6th
'Caraka Saṃhitā' ..	+1st (Present text + 8th)	7th	..	—6th

Nevertheless, the study of the history of science in India remains enthralling. The following words of Filliozat,[1] in the preface to his recent splendid monograph on the theories of classical Indian medicine, are well worth pondering:—

'Some may doubt the legitimacy of placing Indian and Greek science on the same level, preferring to compare the former rather with that of Islam. The common opinion that Indian science lacked originality presupposes that it was derived from Greek science, and is, therefore, sister to the science of the Arabs....

'This problem has been far too much prejudged. Indian scholars, moved by national pride, are prone to maintain that their sciences in high antiquity surpassed even those of today. In the West, on the other hand, many maintain that the

[1] Filliozat, J. La Doctrine Classique de la Medecine Indienne. *Imp. Nat.* (*C.N.R.S. and Geuthner, Paris, 1949*).

spirit of scientific research could only have been born in Europe, and that what science the Indians had they borrowed. In either case the only proofs presented are a few examples claimed as characteristic and used as the basis for generalisations, hypotheses taking the place of facts which are still undiscovered or which people will not take the trouble to seek. Indeed, opinions rest on racial or national preconceptions rather than on a profound comparative study of the two great scientific traditions the value of which is to be determined. One notes also that those who speak with the greatest certainty in these matters are just those who are familiar with only one of the two traditions, knowing the other only by scattered facts, or studies which they are unable to appreciate. To say nothing, of course, of those 'authorities' who know nothing of either of the two traditions about which they speak.

'The greatest historians of science have not always escaped from the inconvenience of knowing only one side of the matter. Paul Tannery, so famous for his studies on ancient mathematics, is an example. We know that the trigonometric sine is not mentioned by Greek mathematicians and astronomers, that it was used in India from the Gupta period onwards (+ third century), that the Surya Siddhanta (+ fourth or + fifth century) gives a table of sines, that the Arab astronomers knew them from their Indian contacts and passed them on to Europe in the + twelfth century, when the work of al-Battani was translated into Latin. The only conclusion possible is that the use of sines was an Indian development and not a Greek one. But Tannery, persuaded that the Indians could not have made any mathematical inventions, preferred to assume that the sine was a Greek idea not adopted by Hipparchus, who gave only a table of chords. For Tannery, the fact that the Indians knew of sines was sufficient proof that they must have heard about them from the Greeks.

'If this is the way we are to argue, there was never any science other than Greek science, and the question whether science has any origins other than the Greek "miracle" is solved in advance. Only a profound study of Indian scientific developments in parallel with those which took place elsewhere about the same times, can reveal the degree of originality of that science, and hence enable us to understand the rôle which India played in the history of the growth of man's knowledge of Nature.'

In the present symposium, the writer on Siam ends, somewhat pathetically: 'At present we all seem to believe that science is something which originated especially in Europe and the Near East, and that the Far East had no share in the building of this most important branch of human knowledge. Yet Asian countries such as India and China were important centres of culture both materially and spiritually. Their peoples had learned how to control the natural world around them, and to live a life in which there was room for leisure, only it seems that the knowledge gained by them never joined up with what we know today as modern science. However, Asian people now find no difficulty in learning science and do not lack ability in scientific research.'

In my opinion, future research on the history of science and technology in Asia will, in fact, reveal that the achievements of these peoples contributed far more, in all pre-Renaissance periods, to the development of world science than has yet been realised. The programme of Filliozat is the answer to the perplexity of Rochanapurananda.

JOSEPH NEEDHAM.

NOTE FROM THE PRESIDENT, NATIONAL INSTITUTE OF SCIENCES, WITH REFERENCE TO THE REVIEW OF THE SYMPOSIUM PAPERS BY DR. JOSEPH NEEDHAM, F.R.S.

Published in *Nature*, Vol. 168, December 15, 1951, p. 1047.

Dr. Joseph Needham has very ably reviewed in *Nature* (Vol. 168, July 14, 1951, p. 64) the series of papers that were read at the Symposium on the 'History of Sciences in South Asia' and has drawn some pertinent conclusions therefrom. He has, however, not been able to gauge the spirit in which the Symposium was held, or expatiate on the new lights that were thrown on the subject. He has, on the other hand, omitted to mention certain salient facts about the organization of the Symposium and the review gives by omission the erroneous impression that it was solely the work of the U.N.E.S.C.O. Science Co-operation Office for South Asia. As Chairman of the Symposium, and now President of the National Institute of Sciences of India, it is incumbent upon me to clear the position as regards the part played by the National Institute regarding the Symposium.

The idea of holding a Symposium on the 'History of Sciences in South Asia' was first mooted by Dr. D. S. Kothari, one of the Secretaries of the Institute, which received the support and co-operation of the U.N.E.S.C.O. Science Co-operation Office in Delhi. Accordingly, the Symposium was held under the auspices of the National Institute of India, in collaboration with the U.N.E.S.C.O. Science Co-operation Office, in Delhi, from the 5th to 7th November, 1950. Facilities for holding the meetings and accommodation for the visiting delegates were generously provided by the University of Delhi. A number of scientists, historians and oriental scholars from India and abroad attended the Symposium and took part in its deliberations. From the mimeographed copies of the papers that had been circulated in advance, it was clear at the very outset that considerable controversy was bound to rage about the dating of the most important texts and to overcome this difficulty a Chronology Committee, consisting of historians and scientists, was appointed at the business meeting prior to the Symposium. This Committee felt that it was very difficult to ascertain with accuracy the dates of Indian literary works supposed to belong to the pre-Christian era. But after discussing the matter at length, they recommended that the chronological table given below, might be taken as a working hypothesis in connection with the discussion of papers of the Symposium. The table is based on the standard work *History of Indian Literature* by Winternitz.

CHRONOLOGICAL TABLE.

Age of the Ṛgveda ..	.. 2000 B.C. to 1500 B.C.
Age of Saṁhitās and Brāhmaṇas	.. 1500 B.C. to 800 B.C.
Age of old Upaniṣads ..	.. 900 B.C. to 599 B.C.
Caraka	.. 100 A.D.
Caraka Saṁhitā, Kernel of	.. 100 A.D. but enlarged in later times.
Suśruta Saṁhitā ..	.. 200 A.D. to 500 A.D.
Vedāṅga Jyotiṣa, Present text	.. 500 B.C.
Śulbha Sūtras ..	.. 500 B.C. and later.
Dharmasūtra ..	.. 600 B.C. to 200 B.C.
Mahābhārata Manusmṛiti Rāmāyaṇa	.. .. 200 B.C. to 200 A.D.

The authors of papers were then asked to revise their papers according to the dates given in the table for various texts but owing to very divergent views, it was

not intended to have all the papers published in full. In reviewing that motley of papers, which were not authorized for publication, and by giving a note that mimeographed copies are available at the U.N.E.S.C.O. Science Co-operation Office in Delhi, Dr. Needham has unknowingly done an injustice to the N.I.S.I. and to the organizers of the Symposium. A summary of the proceedings of the Symposium is under preparation for publication by the N.I.S.I.

The great difficulty with which a scientist is faced for a study of the History of Sciences in India lies in the fact that the available ancient materials and documents are written either in Pali or Sanskrit languages with which he is generally not familiar. He has, therefore, to depend upon oriental scholars for interpretations and commentaries of texts for dating ancient literature. Lack of scientific knowledge among historians and orientalists is somewhat evident which makes it difficult for them to appreciate and evaluate scientific thought of ancient India. In the case of fixing of dates to various texts, there is no unanimity among them. In consideration of this, the participants in the Symposium came to a decision that in future scientists dealing with the History of Sciences should give original texts and the names of the source books for reference by the historians and orientalists.

The scientists in India, as elsewhere, have sound experience of sifting and analysing their data before arriving at any definite conclusions. For instance, my contributions on Fishery Legislation, based on *Arthaśāstra* and the Aśoka Pillar Edict were read by many eminent oriental scholars who have expressed agreement with the interpretations suggested by me, and since their publication, I have received appreciation and agreement from many others. As a matter of fact, whenever any modern conservative view on any matter is challenged, adverse comments are likely to result. It is, therefore, the duty of the scientists to make a correct approach to and appraisal of the scientific knowledge of ancient Indians notwithstanding the prejudices that may exist already about the history of India's cultural heritage and scientific thought. 'The study of the history of science in India', as remarked by Dr. Needham, 'remains enthralling.'

S. L. Hora

I have read Dr. Hora's communication with interest and sympthy. It was a great disappointment to me that I was not able to accept the invitation to participate personally in the Conference, but after the publication of my review in *Nature* I became aware of the work of the Chronology Committee through the report published by Dr Hora at the conclusion of Dr. Wolsky's review in *Archives Internationales d'Histoire des Sciences*, 4, 579 (1951), and I was pleased to find so much concordance of view. My chief object in acceding to the request of the Editors of *Nature* that I should review the conference papers sent to them, which neither the Editors nor I knew were in any sense unauthorized, was to encourage interest in the history of Indian contributions to science.

Joseph Needham

A CONTRIBUTION TO THE LIFE-HISTORIES OF *STELLARIA MEDIA*, LINN. AND *POLYCARPON LŒFLINGIÆ*, BENTH. & HOOK.

By NIRANJAN PAL, *M.Sc., Department of Botany, Calcutta University.*

(Communicated by Dr. I. Banerji, F.N.I.)

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The family Caryophyllaceæ includes about 70 genera and 1,450 species, distributed mostly in the temperate regions of the Northern Hemisphere, of which only 19 genera and 104 species occur in India (Hooker, 1875). In Bengal, the genera *Stellaria* and *Polycarpon* are represented by one species each, namely *S. media*, Linn. and *P. Læflingiæ* Benth. and Hook.

S. media is a member of the sub-family *Alsinoideæ*. It is very widely distributed and is very variable in its external characters. It occurs in waste lands around Calcutta as an annual winter herb.

P. Læflingiæ belongs to the same sub-family, but it is placed under the tribe *Polycarpeæ*. In Bengal, it occurs as an erect or diffuse annual weed in fields and waste places. It is locally known as 'Gima sak' and is used as a green vegetable.

Investigations on the genus *Stellaria* dates from the year 1855 when Tulasne worked on the embryology of the genus. The literature up to the year 1930 has been summarised by Schnarf (1931) and so it need not be repeated here. Since then Joshi (1936) has studied the life-history of *S. media*. According to him, the previous accounts relating to the development of the female gametophyte of this plant as given by Rocén (1927) and Gibbs (1907) are contradictory. Joshi's observations also are not very clear. Maheshwari (1937) states, 'The whole thing needs careful re-investigation. It would not be surprising if in a plant like *Stellaria media* which is so variable in other respects, some difference may occur in the mode of embryo-sac development also, but Joshi's figures do not seem to prove that it is so'.

The genus *Polycarpon* has received very little attention from the embryologists. Rocén (1927) alone has studied the embryology of *P. tetraphyllum*.

MATERIALS AND METHODS.

The materials were collected from different parts of Calcutta, and fixed on bright sunny days between 9 a.m. and 12 noon, during the period January to April, 1948. Formal-acetic-alcohol and Nawaschin's fluid were used as killing and fixing reagents, both of which proved satisfactory. A suction pump was used to facilitate the penetration of the fixing fluid. The floral envelopes of the comparatively bigger buds were removed before fixation. The materials were dehydrated, cleared and embedded in paraffin in the usual way. Sections were cut 8 to 16 μ thick depending on the stage required for study. They were usually stained either with Heidenhain's Iron-alum-Haematoxylin or Newton's Gentign-violet-iodine.

OBSERVATIONS.

(i) *Organogeny of the flower.*—The development of the floral organs appears to be more or less similar in both the plants except for certain minor details. At

first a dome-shaped floral primordium makes its appearance in the axil of a leaf (Fig. 1). Generally it remains enclosed by the leaf-primordium. The different floral whorls arise in acropetal succession from the sides of this primordium. The primordia of the sepals differentiate first (Fig. 1). In *S. media*, the stamens appear next. These are followed by the primordia of the petals (Fig. 14), but in *P. Lœflingiæ*, the sequence is reversed (Fig. 2). The primordia of the carpels in both the species appear last (Fig. 3).

Rendle (1938) states that the floral formula of *S. media* varies considerably. According to him, the flower may have the formula $S_5P_5A_{5+5}G_3$ or $S_5P_5A_5G_3$ or $S_5P_5A_3G_3$. The petals may sometimes be absent. Observations made in the course of the present study based on plants fixed from different localities near about Calcutta show that the flower is typically pentamerous and pentacyclic, the carpels being generally five. It is interesting to note in this connection that Hooker (1875) and Prain (1903) both report variation of the carpels from two to five.

According to Rendle (1938), the flowers of the tribe *Polycarpeæ* are reduced. Occasionally the petals are absent and the stamens are reduced in number. In *P. Lœflingiæ*, however, the following floral formula has been observed in course of the present investigation: $S_5P_5A_5G_3$. Hooker (1875), Prain (1903) and Rocén (1927) reported the number of the carpels as three. Sometimes it has been found to be four in both the plants.

(ii) *Development and structure of microspores.*—At first the anther is composed of a homogeneous mass of meristematic cells. It is somewhat circular in outline, but as it grows, it soon becomes bilobed and later four-lobed. The archesporium is hypodermal in origin (Fig. 4). Four bands of primary archesporial cells, one in each lobe, differentiate in the anther tissue almost simulateneously. Each band is three to six cells long and two to three cells broad. The number of archesporial cells is less in *S. media*. This type of extensive archesporium in an anther has been reported in some of the related families, e.g., Amarantaceæ (Joshi & Rao, 1934; Kajale, 1940*b*), Aizoaceæ (Kajale, 1940*a*), Phytolaccaceæ (Joshi & Rao, 1936) and also in *S. media* by Joshi (1936). The archesporial cells can be easily distinguished by their larger size, greater chromaticity and larger nuclei.

The primary archesporial cells divide periclinally giving rise to a layer of primary parietal or wall cells outside and a layer of primary sporogenous cells inside (Fig. 5). All the archesporial cells, however, do not divide simultaneously. The primary wall cells increase in size and undergo periclinal divisions; the outermost cells divide again and thus three cell-layers of parietal tissue are formed in-between the epidermis and the sporogenous cells of the anthers (Fig. 6). The outermost layer of parietal cells develops into the endothecium which shows the characteristic spiral bands at maturity. The middle layer of cells is crushed in the process of development and the innermost one gives rise to a secretory tapetum. The tapetal cells become binucleate during synizesis of the pollen-mother cells. Schnarf (1931) considers this binucleate secretory type of tapetum to be a characteristic feature of the order Centrospermæ. Joshi (1936) reports the presence of more than two nuclei in a single tapetal cell.

The divisions of the primary sporogenous cells lead to the increase of the microspore-mother cells. In a cross-section of the anther of *P. Lœflingiæ*, generally five microspore-mother cells are found in each lobe, whereas in *S. media* the number is less.

The microspore-mother cells are mostly polygonal in outline and are closely packed together inside the anther loculus without any intercellular spaces. They undergo a fairly long period of rest during which the size of the cells as well as their nuclei increases. Generally one big nucleolus is present in a nucleus. Sometimes in *P. Lœflingiæ*, a small globular bud-like structure is seen associated with the nucleolus which either remains directly attached to or lies near it (Fig. 6). Due to unequal rate of growth of the pollen-mother cells and the tapetal cells, the

latter get detached from the former. In *P. Lœflingiæ*, this occurs during the first division of the pollen-mother cells. It is interesting to note that this phenomenon was also noticed by Joshi (1936). The pollen-mother cells first show signs of rounding up in the diplonema stage. In this stage, the presence of chiasmata in the separating bivalents is seen distinctly in *S. media*, whereas in *P. Lœflingiæ* it is not recognisable (Fig. 15). At diakinesis the bivalents come to lie at the periphery of the nucleus. They are mostly rod-shaped in appearance. The nucleolus disappears. A careful examination shows that the number of bivalents in the pollen-mother cells of *S. media* is 14 and in *P. Lœflingiæ* is 18 (Figs. 7 & 16). This number has also been found during the metaphase of the first division. (Figs. 8 & 17). Both the 1st & 2nd divisions appear to be normal.

Cytokinesis takes place by furrowing. The arrangement of the pollen tetrads is mostly tetrahedral, but in a few cases isobilateral arrangement has also been observed (Fig. 18).

Both in *S. media* and *P. Lœflingiæ*, when first formed, the pollen grains are smooth and more or less triangular in shape. Very soon they increase in size and assume a spherical form. The intine and exine become differentiated. The latter is smooth and thick and shows no markings on its outer surface. In *P. Lœflingiæ*, the pollen grains show a peculiar intermediate structure. They become long and narrow and possess three alternate longitudinal ridges and furrows (Figs. 9 & 10). As they grow, they become gradually spherical in outline and at maturity they are almost spherical. Erdtman (1943) reports two types of pollen grains in this family:—(*a*) *Cribellate* (which is the predominating type) and (*b*) *Colpate* (*tricolpate*). It is interesting to note that in *P. Lœflingiæ*, the pollen grains become *tricolpate* in an intermediate stage of their development.

The germ-pores are somewhat circular in outline and provided with a special marginal area as mentioned by Erdtman (1943). The number of pores in the pollen grains of *P. Lœflingiæ* is only three, but in *S. media* it is six or more. In *S. aquatica*, the number has been reported to be 12. The mature pollen grains are 20–35 μ in diameter in *S. media* and 15–30 μ in *P. Lœflingiæ*. It is interesting to recall that the diameter of the pollen grains has been recorded to be 35 μ in *S. aquatica* and 29 μ in *S. uliginosa*. According to Joshi (1936) the pollen grains of *S. media* vary from 18 to 30 μ in diameter.

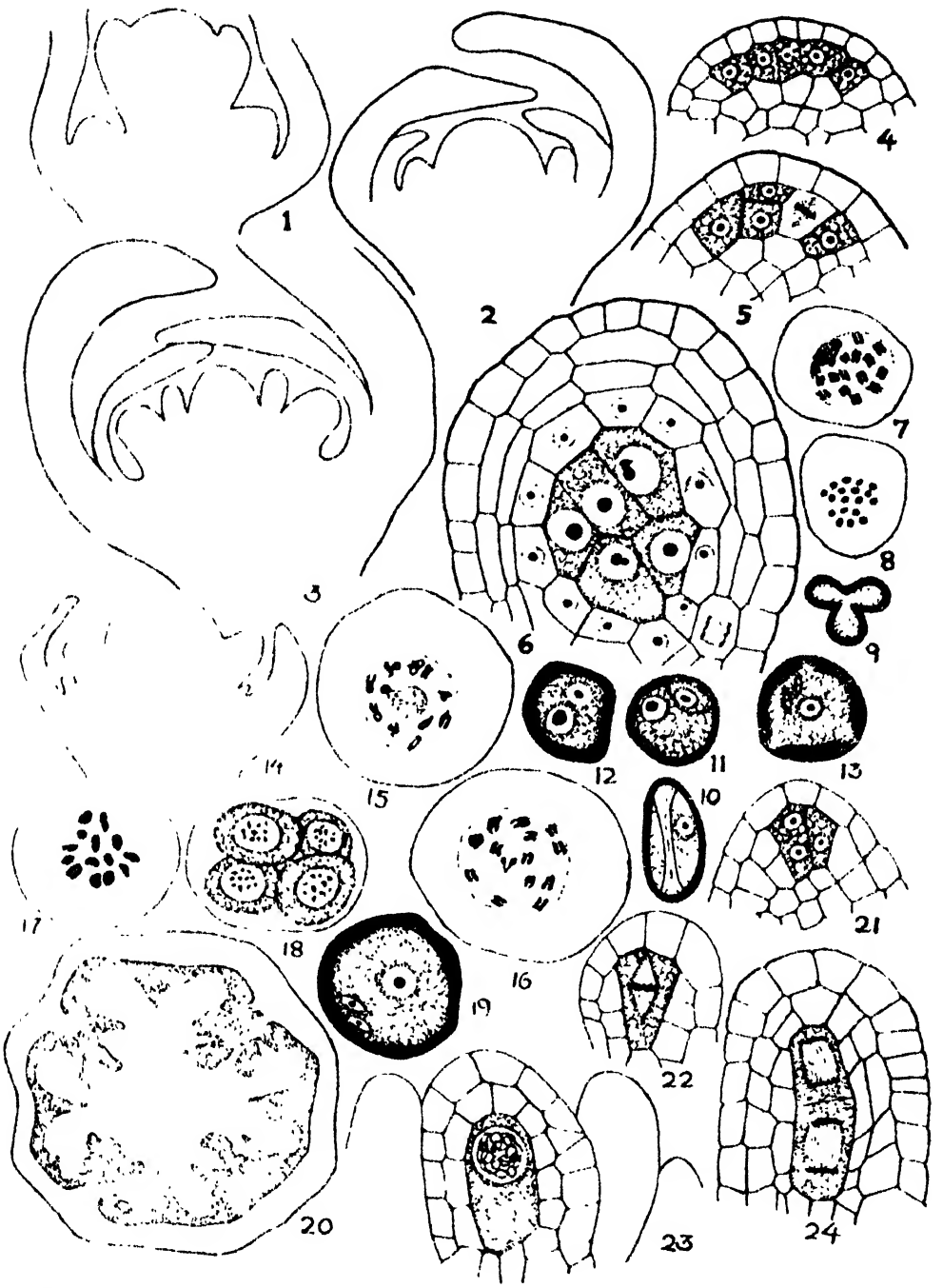
In both the plants, degeneration of the microspores while inside the microsporangium is a common phenomenon. They may degenerate in the tetrad stage or at a later stage, and the number of such degenerating microspores was found to be few or many inside a microsporangium. This phenomenon was also noted by Joshi (1936) in *S. media*.

The nucleus of the pollen grains moves towards the periphery before division; a small generative nucleus is cut off which becomes delimited by a cytoplasmic membrane as is commonly seen in other plants (Fig. 11). Later on, the generative and the vegetative nuclei lie side by side in the cytoplasm (Fig. 12). The generative nucleus next divides to form two minute lens-shaped male nuclei (Figs. 13 & 19).

The mature pollen grains are rich in starch grains. They attain maturity when the embryo-sacs of the same flowers are in 1- or 2-nucleate stages. They are shed in the 3-nucleate stage which is considered by Schnarf (1931) to be a characteristic feature of the order Centrospermæ.

(iii) *Development and structure of the ovule.*—The placenta is very massive and is composed of large cells surrounding the central vascular strand. In later stages of development it shows many lysigenous cavities in the peripheral region.

The placentation is axile in both the species in the beginning, with two rows of ovules in each cell (Fig. 30). In *P. Lœflingiæ*, the number of the septa in the ovary is three and each of them is composed of about five layers of cells. These partition walls persist in the ovary even in the post-fertilisation stages. Later, when the embryo is fairly developed, these partition walls become crushed and



FIGS. 1–13. *Polycarpon Loeflingiae*. Figs. 1–3. Developmental stages of the floral parts. × 120. Figs. 4–6. Development of microspore-mother cell. × 700. Figs. 7 & 8. Diakinesis and Metaphase I (polar view). × 1500. Figs. 9–13. Development of pollen grains, Fig. 9, being T.S. of a ridged pollen grain. × 700.

FIGS. 14–24. *Stellaria media*. Fig. 14. Development of floral organs. × 120. Figs. 15–17. Diplotene, Diakinesis and Metaphase I of pollen-mother cell. × 1500. Fig. 18. Isobilateral pollen tetrad. × 1500. Fig. 19. Mature pollen grain. × 700. Fig. 20. T. S. of ovary showing the development of free central placentation from the axile condition. × 90. Fig. 21. Multiple archesporium in an ovule. × 700. Fig. 22. One-celled archesporium in divisional stage. × 700. Figs. 23–24. Stages of reduction division in the megaspore-mother cell. × 700.

obliterated, and then only the placentation becomes free central. But in *S. media*, the septa which in the early developmental stages are five in number and are absent at the top of the ovary, degenerate very soon. As a result of this, the axile placentation becomes free central at an early stage of development of the gynœcium. The signs of degeneration of the septa appear with the differentiation of the megaspore-mother cell in the ovules and by the time the chalazal megaspore begins to enlarge into embryo-sac, the ovary is completely one-chambered (Fig. 20). It may be pointed out here that Rocén (1927) describes a three chambered ovary in *S. media*.

The ovules arise as minute protuberances of the placenta. At first the tissue is uniform in structure with a tapering apex but soon the apical part of the tissue enlarges and differentiates as the massive nucellus. The integuments which are two in number, arise from the base of the thick nucellus one after another in basipetal succession. They are first noted as annular outgrowths after the differentiation of the primary archesporial cells. Each integument is composed of two layers of cells which seems to be a characteristic feature of the order. The inner integument soon covers the entire nucellus. Its apical region continues to grow further and forms a cap-like structure over the nucellus resulting in an elongated micropyle. It is four cells thick in *S. media* and three in *P. Lœflingiœ*. The outer integument does not overgrow the inner, and so takes no part in the formation of the micropyle (Figs. 23 & 40). In *S. media*, during the later stages of the development of the ovule some yellow granules become deposited in the cells of the outer layer of the outer integument and in the inner layer of the inner integument. In *P. Lœflingiœ*, no such deposition is, however, noted in the latter layer. The nucellar cap is composed of four layers of cells in *S. media*. In *P. Lœflingiœ*, the sub-epidermal cells of the cap degenerate and the embryosac lies next to the epidermis, the cells being elongated radially, which was also found in *Sisuvium portulacastrum* by Kajale (1940*a*) and in *Trianthema monogyna* by Bhargava (1935).

In *P. Lœflingiœ*, a peculiar structure is seen associated with the funicle. After the differentiation of the integuments, the ovule assumes an anatropous form. At this stage the funicle is seen to branch at the point of attachment of the ovule on the outer side. This branch increases in size, becomes tapering and extends up to the chalazal end of the ovule (Fig. 31).

(iv) *Megasporogenesis.*—The primary archesporium differentiates in the ovule even before the appearance of the integuments. Generally it consists of a group of hypodermal and sub-hypodermal cells varying in number from 1 to 7, but in *S. media* the number varies from 1 to 4 (Figs. 21, 22, 32 & 33). Rocén (1927) found only one archesporial cell in *P. tetraphyllum*. On the other hand, Joshi (1936) records 4–6 archesporial cells in *S. media*. Dahlgren (1916) and Rocén (1927) also described multicellular archesporium in different species of *Stellaria*.

All the archesporial cells do not behave in the same manner. In *S. media*, one of the median hypodermal cells cuts off a parietal cell outside and then functions as the megaspore-mother cell. With the increasing size of this mother cell, the other archesporial cells become indistinguishable. In no case, more than one functional archesporial cell has been found. But in *P. Lœflingiœ*, their behaviour is different. All those in the hypodermal position cut off parietal cells and thus several megaspore-mother cells are formed. However, further growth of most of them is arrested. Generally only the median one grows further and as a result of this the other megaspore-mother cells and the remaining archesporial cells become indistinguishable. As has been observed by Rocén (1927) in *P. tetraphyllum*, not more than one functioning megaspore-mother cell is met with. The cells underlying the megaspore-mother cell are somewhat larger than the surrounding nucellar cells. These appear to be archesporial in origin, having been displaced by the developing megaspore-mother cell. Their number and arrangement are variable (Figs. 34–38).

In *S. media*, a normal linear tetrad of megaspores is formed by the reduction division of the megaspore-mother cell of which only the chalazal one functions to give rise to a normal type of embryo-sac. Different stages of this division have been observed during the present investigation (Figs. 23–25). But in *P. Lœflingiæ*, the behaviour of the megaspore-mother cell during the reduction division is variable. After the heterotypic division, only the lower dyad cell divides again homotypically to give rise to two megaspores. Thus a row of three cells, i.e., one micropylar dyad and two chalazal megaspores is formed (Fig. 40). In this case only the lowermost megaspore functions to give rise to a normal type of embryo-sac (Fig. 41). But in other cases, a normal row of four megaspores is seen of which the micropylar megaspore is functional (Fig. 42). The presence of a row of two megaspores and one micropylar dyad (which may be 2-nucleate) and a normal linear tetrad of megaspores in the same plant has also been noted in the related families, e.g., Amarantaceæ (Joshi & Rao, 1934), Aizoaceæ (Kajale, 1940*a*) and Nyctaginaceæ (Rocén, 1927).

(v) *Development and organisation of the embryo-sac.*—The development of the embryo-sac is of the 'Normal type'. The nucleus of the functioning megaspore lies in the centre of the cell and enlarges. Small vacuoles develop at the two poles of the cell. The nucleus divides; the daughter nuclei migrate to the two opposite poles of the embryo-sac. The embryo-sac continues to increase in size and later only a single vacuole is seen in the centre. An abnormal case has been observed in *P. Lœflingiæ* where the two nuclei migrated towards the two lateral sides of the embryo-sac and consequently two big vacuoles appeared at the two poles. Some of the four-nucleate embryo-sacs of *P. Lœflingiæ* contain conspicuous bigger nuclei than others (Figs. 43 & 44). On reaching the two poles, each of the daughter nuclei of the 2-nucleate embryo-sacs divide twice to form an eight-nucleate embryo-sac (Figs. 28 & 45).

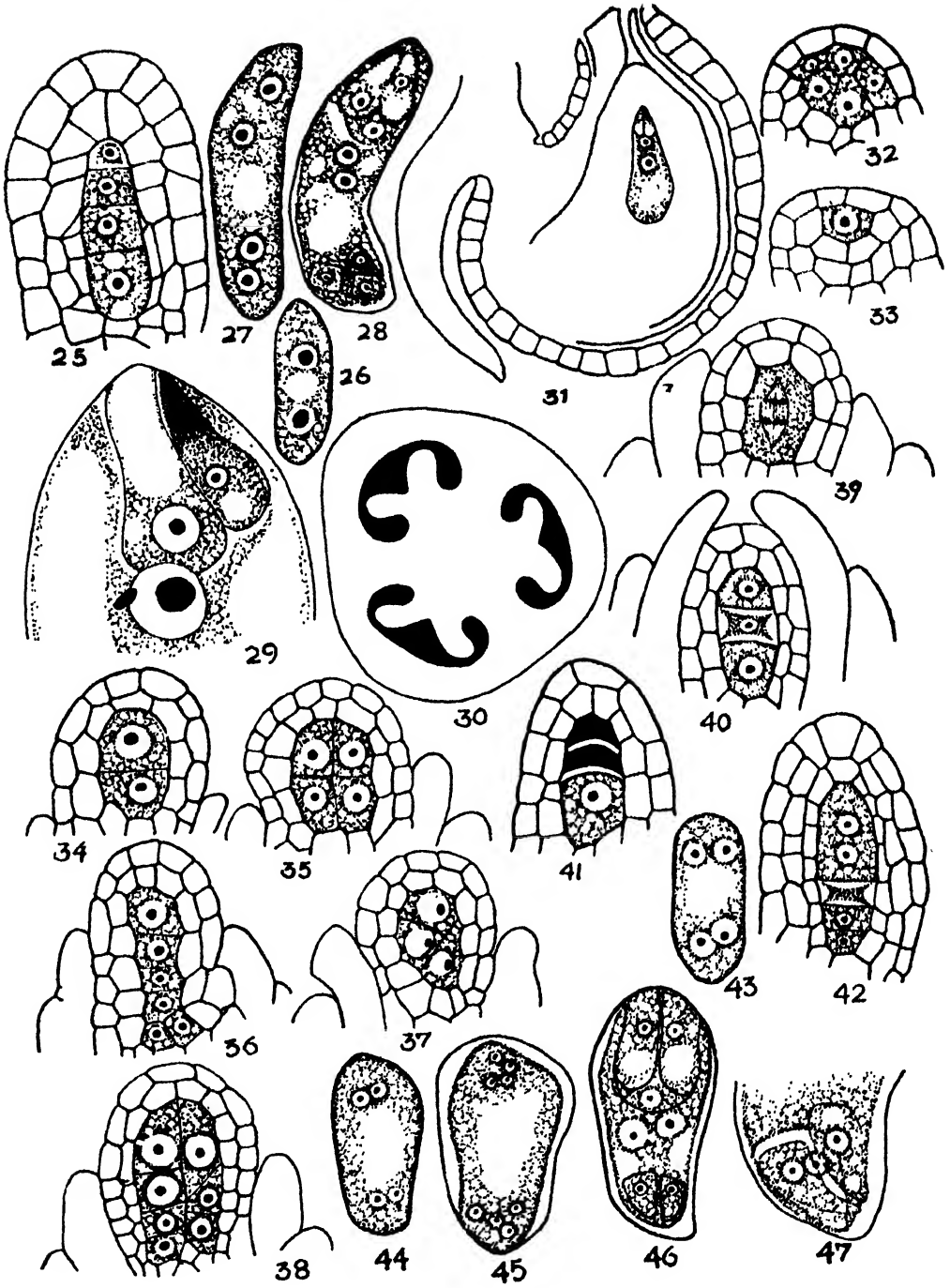
The organisation of the embryo-sac is of the normal angiospermous type. The synergids are pear-shaped with vacuoles at their chalazal ends. Egg-like synergids with vacuoles at the micropylar end have also been noted in *S. media*. In other cases, vacuoles are found at both ends (Fig. 28). In form the egg appears somewhat similar to that of the synergids, the position of the vacuole is, however, different (Fig. 29). The egg is mostly covered by synergids, only the rounded distal end being visible (Figs. 28 & 46). The secondary nucleus is comparatively big and lies very near the egg apparatus (Fig. 29). The antipodal cells are somewhat triangular in shape and lie together at the chalazal end. Their shape and arrangement are variable (Figs. 28, 46 & 47). They are ephemeral in nature and at the time of fertilisation no trace of them is found. It is interesting to note that in *P. tetraphyllum* Rocén (1927) observed three free antipodal nuclei.

The mature embryo-sac is curved like the ovule which is hemianatropous in form. The curvature is initiated at the four-nucleate stage and after fertilisation it becomes very prominent.

(vi) *Fertilisation.*—Fertilisation is porogamous and normal. The pollen tube passes through one of the synergids. Double fertilisation has been observed in *S. media* (Fig. 29).

(vii) *Development of the endosperm.*—The endosperm is of the nuclear type. The division of the primary endosperm nucleus takes place before the first division of the fertilised egg. Numerous free nuclei are formed which are mostly aggregated at the chalazal and micropylar ends of the embryo-sac. All the endosperm nuclei in an embryo-sac divide almost simultaneously.

Wall-formation around the endosperm nuclei is first noted when the cotyledonary initials are well-differentiated in the embryonal mass. The process starts at the micropylar region and extends towards the other end. In *S. media*, wall-formation does not take place at the chalazal region which is absorbed in the free-nuclear condition by the growing embryo. The endosperm cells are very



FIGS. 25–29. *Stellaria media*. Fig. 25. Linear tetrad of megaspores. ×700. Figs. 26–28. Development of the embryo-sac. ×700. Fig. 29. Double fertilisation. ×700.

FIGS. 30–47. *Polycarpon Læflingiæ*. Fig. 30. T.S. of ovary showing axile placentation. ×90. Fig. 31. Section of an ovule showing the outgrowth (aril) from the funicle. ×260. Fig. 32. Multiple archesporium in the ovule. ×700. Fig. 33. One-celled archesporium in the ovule. ×700. Figs. 34–38. Different arrangements of the megaspore-mother cells and the primary archesporial cells. ×700. Fig. 39. Reduction division of megaspore-mother cell. ×700. Fig. 40. A row of the micropylar dyad cell and two chalazal megaspores. ×700. Fig. 41. Functional chalazal megaspore with degenerating dyad cell and other megaspore. ×700. Fig. 42. Development of the embryo-sac from the micropylar megaspore of a complete linear tetrad. ×700. Figs. 43–44. Size variation of the nuclei in 4-nucleate embryo-sacs. ×700. Fig. 45. 8-nucleate embryo-sac. ×700. Fig. 46. Mature embryo-sac. ×700. Fig. 47. Structure and arrangement of antipodals. ×1500.

rich in cytoplasm and starch grains. The embryo during its development destroys the endosperm tissue. Only a thin layer of endosperm cells is, however, found to be capping the radicle of the mature embryo in *S. media*. The embryo-sac ultimately assumes a horse-shoe-shaped form.

(viii) *Development of the embryo.*—The fertilised egg rests for some time before commencing activity. It elongates rapidly and has a broadened apex. No trace of synergids is noted at this stage. The first division in the oospore takes place when the primary endosperm nucleus has divided twice in succession (Fig. 48). This division is always followed by the formation of a transverse wall giving rise to a primary embryonal cell *ca* and a primary suspensor cell *cb* (Figs. 49 & 72). The two cells behave differently during further development in the two plants.

In *S. media*, the basal cell does not divide further, but elongates and becomes hypertrophied The apical cell alone divides in a transverse plane to give rise to *cc* and *cd* (Figs. 49 & 50). These cells next divide by transverse walls either simultaneously or one after the other and a five-celled pro-embryo is formed which remains as such until the longitudinal divisions take place (Figs. 50–53). In a solitary instance, however, the apical cell *cc* was found to divide longitudinally (Fig. 54).

For the sake of convenience the specific cells of the pro-embryo are designated by symbols used by Souèges (1924) for *Sagina procumbens* and are as follows (from apex to base in the five-celled condition): *l*, *l'*, *m*, *ci* and *cb*.

The first two longitudinal walls appear in *l'* and *m* at right angles to each other (Fig. 55). In a few cases the apical cell is found to have divided longitudinally prior to either of *l'* or *m* (Fig. 56). Almost simultaneously with the longitudinal divisions in *l'* and *m*, the cell *ci* also divides transversely to give rise to *n* and *n'*. This cell *n* is the new fourth cell from apex which forms the hypophysis (Fig. 55). The other cell *n'* may or may not undergo any more transverse division. If it divides, it does so either simultaneously with or after the longitudinal division of *n* (Figs. 59 & 60). These daughter cells of *n'* which may be called *o* and *p* (Fig. 61), may or may not divide further. When they divide, they do so always in a transverse direction and the divisions may take place once either in *o* or in both the cells (Figs. 63 & 65). Thus the suspensor may be 2–5 cells long. Rocén (1927) also describes a considerably long suspensor in *S. media*.

The next longitudinal division takes place in the apical cell (Fig. 55). In one isolated case, however, the hypophysial cell *n* was observed to have divided longitudinally prior to the apical cell (Fig. 57).

Quadrant formation in *l'* and *m* takes place in close succession which takes place first mostly in *m* (Figs. 58 & 59). These vertical walls are at right angles to the first longitudinal walls in the corresponding cells. Longitudinal division is next observed in the hypophysial cell *n*. This division occurs almost simultaneously with or before the quadrant formation in the penultimate cell *l'* (Fig. 59). The third quadrant appears in *n* (Fig. 61), which may be considered as premature and differing from the sequence observed in *Sagina procumbens* by Souèges (1924). In the meantime, the cells of the third tier *m* divide periclinally to give rise to an octant tier (Fig. 61). Soon the penultimate tier *l'* attains the same condition (Fig. 62). Meanwhile the apical tier *l* becomes four-celled (Fig. 62). Afterwards these four cells divide again obliquely with the production of four inner and four outer cells. Thus the dermatogen differentiation proceeds in an acropetal order, which is a characteristic feature of the order.

In the meantime the differentiation of the other two histogenic layers begins. The dermatogen cells divide only by anticlinal walls and so do not contribute to the inner tissues of the embryo. The inner two layers of cells divide again in a periclinal direction to give rise to an outer layer of cells or periblem and two inner layers of cells or plerome (Fig. 63). Afterwards, this outer layer divides again

periclinally to give rise to a two-layered periblem (Fig. 65). The cells constituting the plerome divide in all directions (Figs. 63 & 64).

The octant derived from the apical cell *l* divides at a slow rate and gives rise only to the stem-apex of the embryo at a very late stage of development. The activity of the tier *l'* is not rapid in the early stages. Later it gives rise to the cotyledonary initials which grow very vigorously and develop into two large cotyledons. The third tier *m* divides actively in both directions and differentiates into the hypocotyl and radicle, except the dermatogen layer of the root-apex. The hypophysial cell *n* gives rise to a quadrant in an early stage of the development of the embryo as mentioned previously. Then the activity of this tier is arrested for sometime, the cells dividing again tangentially, only when the cotyledonary initials are about to differentiate. The inner cells contribute to the dermatogen of the root-apex and the outer ones give rise to the median portion of the root cap (Fig. 66). The other cells taking part in the formation of the root cap are the lowermost two tiers of dermatogen cells derived from *m*. These cells, too, in their turn, undergo tangential divisions and differentiate in the same manner as *n* (Fig. 67).

The primary basal cell *cb* does not divide at all, but enlarges immensely. It has a very large nucleus situated near the centre surrounded by dense cytoplasm (Figs. 49–65). The nucleus becomes granular at maturity, takes deep stain and appears like a bunch of small beads. After the initiation of the cotyledonary initials, the activity of *cb* diminishes gradually and ultimately the growing embryo gets free due to the breaking down of the latter. Otherwise the suspensor cells gradually degenerate and in the mature seed their remnants are unrecognisable.

The form of the mature embryo is somewhat semi-circular (Fig. 68). The inner cotyledon is seen to be smaller than the outer. Starch grains are deposited in the embryo chiefly in the cells of dermatogen and cotyledons. The embryo completely absorbs the endosperm tissue except a small portion which forms a cap-like structure over the root-apex.

In *P. Lœflingiæ*, both the primary suspensor cell and the primary embryonal cell divide transversely again. The basal cell usually divides first though simultaneous divisions and even the reverse sequence are not uncommon (Figs. 72–74). The four cells of the pro-embryo may be disignated as *l*, *l'*, *m* and *ci* from apex to base, as used by Souèges (1920) for *Chenopodium Bonus-Henricus*. The penultimate cell *l'* divides transversely to give rise to l_1' and l_2' and thus a five-celled pro-embryo is formed (Figs. 75 & 76). The first longitudinal wall in the apical cell *l* appears in this five-celled pro-embryo (Fig. 76) but in a few cases the latter may increase in length due to the transverse divisions of *ci* or of both *ci* and *m* before the commencement of any longitudinal division (Figs. 77 & 78). The second longitudinal division occurs in the penultimate cell l_1' (Fig. 79). In a solitary instance, however, the penultimate cell was seen to divide longitudinally prior to the apical one (Fig. 93). Meanwhile the two basal cells *m* and *ci* divide transversely (Figs. 79 & 80). Soon the two cells of the apical tier *l* divide again vertically and an apical quadrant is formed (Fig. 80). The next transverse division occurs in l_2' giving rise to l_3' and l_4', l_3' being adjacent to the penultimate cell l_1' and the other being the hypophysial cell (Figs. 80 & 81).

After this the cells of the penultimate tier l_1' divide again vertically and thus a second quadrant is formed (Fig. 82). Soon l_3' undergoes a longitudinal division followed by a similar division in the hypophysial cell l_4' (Figs. 82–84). The latter, however, may remain undivided in a few cases until the apical octants are formed (Fig. 85). Thus the longitudinal divisions in the four cells take place in a basipetal succession as found in *Boerhaavia* by Kajale (1938). In most of the other investigated plants of the order, however, the order of these divisions is somewhat acropetalous (Souèges, 1920 and 1924; Joshi and Rao, 1934 and 1936; Kajale, 1935 and 1940*b*).

Next, the apical quadrant gives rise to an octant by the formation of transverse walls. Thus two tiers of quadrants arise from the apical cell *l* (Fig. 85). Almost simultaneously with it the cells of the penultimate tier l_1' divide by periclinal walls to give rise to another octant (Fig. 85). All the cells, however, do not divide simultaneously. Soon the lower four cells of *l* divide periclinally to give rise to another penultimate octant tier (Fig. 86). Further divisions in the tier l_1' take place by transverse walls and thus two tiers of cells are also derived from the penultimate cell of the five-celled pro-embryo (Fig. 87). Later, the four apical cells of *l* divide by oblique walls (Fig. 88). Thus the dermatogen differentiation proceeds in an acropetal succession as seen in *S. media* and other plants of the order. It is interesting to note, however, that the initiation of periclinal divisions occurs simultaneously with the formation of transverse walls in the apical and penultimate tiers, i.e., *l* and l_1'. Moreover, though the appearance of vertical walls is in basipetal succession, the periclinal walls appear in an acropetal order.

After the differentiation of the dermatogen layer, the other histogenic layers differentiate in the same sequence as found in *S. media*. The two tiers of cells of *l* divide chiefly in vertical directions and later differentiate into the stem-tip and the cotyledons of the embryo. The former is very small even when the latter are fairly large. The stem-tip arises from the central part of the apical tissue and the cotyledonary initials from the peripheral region of the latter. The next two tiers of cells are derived from the penultimate cell l_1' which gives rise to the hypocotyl. The third cell l_2' shows less activity after the quadrant formation. It gives rise to an octant tier only in later stages of embryo-development and develops into a semi-circular body which ultimately gives rise to the radicle.

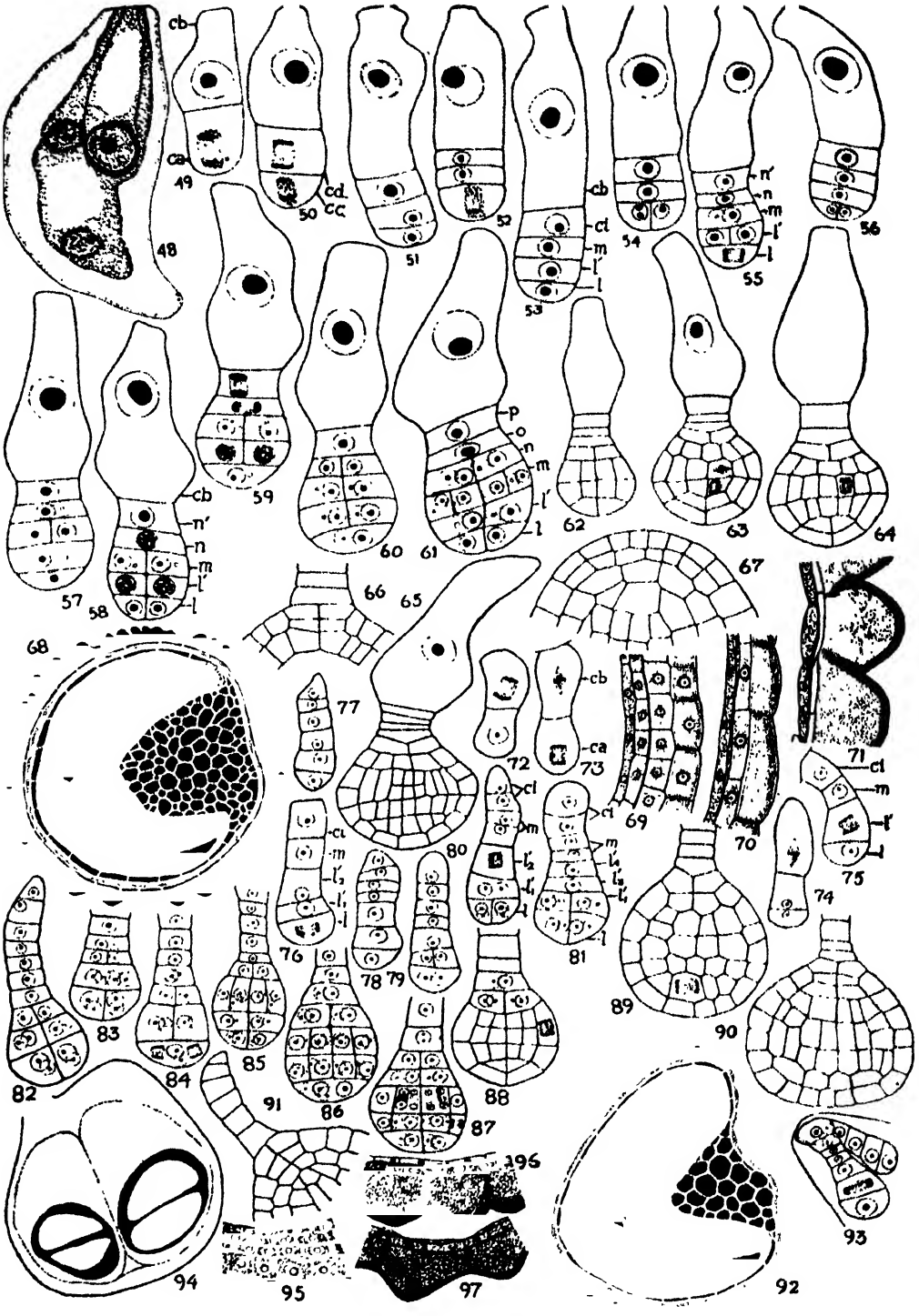
The first longitudinal division in the hypophysial cell l_4' takes place only after the formation of two quadrants in the apical cells. The next longitudinal divisions commence only after the differentiation of the histogenic layers in the embryo (Fig. 89). Afterwards these cells divide tangentially. The inner cells give rise to the dermatogen of the root-apex and the outer ones to the rootcap (Figs. 90 & 91).

As mentioned previously, the divisions of the basal cells of the five-celled pro-embryo are initiated simultaneously with those of the apical cells. These cells divide always transversely and ultimately a row of 5-10 suspensor cells is derived as found in *P. tetraphyllum* by Rocén (1927). In a very few cases any one of the suspensor cells may divide once in a longitudinal direction but the suspensor never becomes biseriate or massive. Unlike *S. media*, the primary suspensor or basal cell divides transversely in this plant to give rise to all of the suspensor cells. Rocén (1927) describes a weak haustorial basal cell in *P. tertraphyllum*, which was not found in the present material. The mature embryo is not exactly semi-circular, but it is bent prominently in the hypocotylar region (Fig. 92). In *P. tertraphyllum*, Rocén (1927) described a slightly curved embryo. The structure of the cotyledons is similar to that of *S. media*. Starch grains are found in the cells of dermatogen, plerome and the cotyledons. The endosperm tissue is completely absorbed by the growing embryo and nothing is left even in the root-apex area. The size of the embryo is much smaller than that of *S. media*.

(ix) *Polyembryony.*—A case of polyembryony has been observed in *P. Lœflingiæ*. Two pro-embryos have been observed side by side in the same embryo-sac (Fig. 93). One is 7 cells long with the penultimate cell undergoing the first longitudinal division and the other consists of only 5 cells in a row. The bigger pro-embryo appears to have developed in the usual way from a normal fertilized egg. The origin of the other is perhaps from one of the synergids.

Double nucelli in one ovule have also been found in both the plants, each containing an embryo-sac in advanced stage of development (Fig. 94).

(x) *Development and structure of the seed.*—The mature seed contains a large quantity of perisperm which extends from the base to the centre and is enclosed by the mature embryo from three sides. The embryo is somewhat cylindrical



Figs. 48–71. *Stellaria media*. Fig. 48. Elongation of the oospore in a curved embryo-sac. Two endosperm nuclei in the dividing stage. ×200. Figs. 49–68. Various stages in the development of the embryo. Figs. 49–61. ×200. Figs. 62–65. ×125. Figs. 66–67. ×200. Fig. 68. ×25. Figs. 69–71. Development of the seed coat. Figs. 69 and 70. ×125. Fig. 71. ×70.

Figs. 72–97. *Polycarpon Læflingiæ*. Figs. 72–92. Various developmental stages of the embryo. Figs. 72–91. ×200. Fig. 92. ×30. Fig. 93. A case of polyembryony showing two pro-embryos in a single embryo-sac. ×200. Fig. 94. Double nucelli with two embryos. ×30. Figs. 95–97. Development of the seed coat. Fig. 95. ×200. Fig. 96. ×125. Fig. 97. ×70.

and narrow, and lies at the peripheral region of the seed encircled by a single layer of perisperm cells (Figs. 68 & 92).

Two cell layers constitute the testa in both the plants. The cells of the outer layer become very big in size at maturity. Some yellow granular substance begins to be deposited in these cells from a very early stage. The deposition begins at the chalazal end and extends towards the micropyle. In the meantime marked changes occur in the cell walls. The outer walls of these rectangular cells begin to bulge out along with the deposition of the granules. At this time the nucleus lies near the outer wall of the cell (Figs. 69 & 95). Later, the convex walls of the cells become greatly thickened; the cells become completely filled up with the yellow particles and the nuclei become invisible. The cells fuse laterally with each other to form a homogeneous mass of thick brown testa (Figs. 70, 71, 96 & 97). The inner layer of cells of the outer integument remains unthickened.

The tegmen is altogether absent from the seeds of *P. Lœflingiæ*. In course of development both the cell layers of the inner integument of the ovule are compressed and finally crushed. In *S. media*, a single layered tegmen is present. The outer layer is destroyed during the developmental stages of the seed by the compression of inner and outer tissues. The inner layer of cells of this integument becomes hardened by the deposition of some yellow particles probably of the same nature as seen in the outermost cell layer of testa (Figs. 69–71). The structure of the seeds of *S. media* is similar to that of *S. holosia* studied by Rocén (1927).

Discussion.

According to Rendle (1938), the placentation of the order Centrospermæ is at first axile and later the free-central placentation is derived by the dissolution of the septa of the ovary. This condition has been substantiated by the present study. It is notable, however, that the axile placentation is retained in *P. Lœflingiæ* till the end. In *P. tetraphyllum*, Rocén (1927) observed the other type.

Rocén (1927) first determined the chromosome number of *S. media* as $2n = 40$. This was confirmed by Joshi (1936). Based on Paterson's (1936) account, Darlington and Janaki-Ammal (1945) report the $2n$ number to be 40 and 44. Study of meiosis during this investigation clearly showed the presence of 14 bivalents in diakinesis and in the metaphase of first division. Darlington and Janaki-Ammal (1945) also report the chromosome number $n = 10$, 11, 12 and 13 in the genus *Stellaria*: the number $n = 14$ as determined in the present investigation, therefore, tends to show that there is considerable aneuploidy within the genus. It can, therefore, be suggested that *S. media*, as occurs in lower Bengal, belongs to a different ecological species. The chromosome number in *P. Lœflingiæ* in the present study has been found to be $n = 18$. This apparently has not been recorded before. The number $n = 18$ has also not been previously recorded in this family, though the monoploid numbers 10, 12, 13, 14, 15 & 17 appear to be common.

The number of integuments of the ovule has been found to be two only. In *P. Lœflingiæ*, however, an additional structure is found developing from the funicle near the base of the ovule and growing to some extent parallel to the chalazal surface of the latter. It, however, never grows long enough to function as an aril, but soon becomes arrested in its development. Kajale (1940*a*) also found a similar structure in *Sisurium portulacastrum* where it covers only ⅓ of the ovule. He regards this as an aril. The presence of a third integument or aril was reported in *Trianthema monogyna* by Bhargava (1935).

In *Silene*, *Melandrium*, *Agrostemma*, *Dianthus*, *Lychnis* and *Scleranthus* (Schnarf, 1931) more than one archesporial cells were found by several investigators. According to Gibbs (1907), there is only one primary archesporial cell in the ovule of *S. media*. In the present study the number is found to be one or more, frequently 2 to 4. Joshi (1936) also records the number to be 4 to 6. Dahlgren (1916) and

Rocén (1927) have found several archesporial cells in *S. graminea*, *S. media* and in some other plants of the family. Perotti (1913) holds the same view. It is interesting to note that in *P. Lœflingiæ* this number is still greater. Rocén (1927), however, records the presence of single archesporial cell in *P. tetraphyllum*. All the archesporial cells do not develop in the same manner. In *S. media* only one hypodermal archesporial cell functions as a megaspore-mother cell after cutting a parietal cell as has been previously observed by Joshi (1936). This agrees with the observations of Gibbs (1907) on *S. media* and Souèges (1924) on *Sagina procumbens*. Rocén (1927) who has worked on a number of species of the family did not, however, find this condition except in *Gypsophila*. Schnarf (1931) believes the non-occurrence of the parietal cell in Caryophyllaceæ as uncertain or a false record. The number of megaspore-mother cells in *P. Lœflingiæ* may be more than one as stated before. The presence of more than one megaspore-mother cells in Caryophyllaceæ has also been mentioned by Schnarf (1931).

Gibbs (1907) described the development of embryo-sac in *S. media* as of the 'Adoxa type' (then called 'Lilium type'). Later Rocén (1927) contradicted her and described the embryo-sac development of the same and many other members of the family as of the 'Normal type'. Joshi (1936), however, gave an altogether different account. According to him, the development of the embryo-sac of the plant is either of the 'Adoxa type' as described by Gibbs or less frequently of the 'Allium type', but it never follows a 'Normal type' of development as described by Rocén. He could not get a row of three or four megaspores. Yet he mentions about the possibility of a 'Normal type' of development of the embryo-sac in this species on account of its great morphological variability. The present investigation conclusively proves a 'Normal type' of development of female gametophyte in *S. media*. Rocén's observations are, therefore, correct. It is interesting to note that in *P. Lœflingiæ* generally a complete megaspore tetrad is lacking, as the micropylar dyad cell generally does not divide, but degenerates as such. In the few cases, where a complete megaspore tetrad has been noted, it is the micropylar megaspore and not the chalazal one, which functions to give rise to the 'Normal type' of embryo-sac. Rocén (1927), however, states that the micropylar dyad cell in *P. tetraphyllum* always divides without wall formation and the chalazal megaspore functions.

Gibbs (1907) opined that the primary endosperm nucleus in *S. media* divides later than that of the oospore. Joshi (1936) contradicted her. The present investigation supports Joshi's view. Based upon the nature of cell formation in the endosperm tissue Rocén (1927) has placed the genus *Stellaria* and the tribe *Polycarpeæ* under the 'Heliosperma type', but the present investigation shows that the cell-formation in the endosperm tissue of *P. Lœflingiæ* takes place throughout the embryo-sac and so following Rocén's system of classification this plant should be placed under the 'Silene type' and not under the 'Heliosperma type'. The formation of a diverticulum of the embryo-sac which has been recorded in several plants of the family has not been observed in the present material.

The two plants studied differ widely in their embryogeny. The sequence of transverse divisions in the oospore to form a filamentous pro-embryo is altogether different. In this respect and in the later development of the embryo *S. media* somewhat resembles *Lychnis alba* (Devine, 1950) and *Sagina procumbens* (Souèges, 1924). But the sequence of cell-divisions in *P. Lœflingiæ* follows *Portulaca sp.* (Kajale, 1942) and *Chenopodium Bonus-Henricus* (Souèges, 1920) in some respects. The number of apical cells taking part in the formation of the embryo proper is found to be more or less constant for certain members of the order, varying from three to five. In both the plants investigated this number was found to be four. Of course, the nature and differentiation of these cells varies widely in different members. In *Sagina procumbens* (Souèges, 1924), *Lychnis alba* (Devine, 1950) and *Stellaria media* the primary embryonal cell gives rise to all the four apical cells as

well as the suspensor cells except the basal one. In the latter, the number of the suspensor cell may be in some cases three or four or even one. But in *P. Læflingiæ* all the suspensor cells are derived from the primary suspensor or basal cell and the four apical cells taking part in the formation of the embryo proper are derived from the primary embryonal cell.

According to Johansen's (1945) classification, the sequence of embryo-development of *S. media* follows the 'Caryophyllad type' as found in other plants of the family, but in *P. Læflingiæ* it is after the 'Solanad type'. Following his (1950) 'Law of Destination' the embryonomic formulæ of *Stellaria media* and *Polycarpon Læflingiæ* may be recapitulated in the following table to show the relationship of the different organs of the embryo to that of the cells of the pro-embryo, which is, however, very different in the two plants.

I. First Cell Generation: Pro-embryo of two cells disposed in two tiers. (The basal cell is omitted in *S. media*.)

S. media	*P. Læflingiæ*
ca—pvt + pco	*ca—pvt + pco + phy + icc + iec + co*
cb—phy + icc + iec + co + s	*cb—s*

II. Second Cell Generation: Pro-embryo of four cells disposed in four tiers.

S. media	*P. Læflingiæ*
l—pvt	*l—pvt + pco*
l′—pco	*l′—phy + icc + iec + co*
m—phy + icc + iec	*m—* } *s*
ci—co + s	*ci—* }

III. Third Cell Generation.

S. media (Embryo of 7-8 cells disposed in 5 tiers).	*P. Læflingiæ* (Embryo of 5-6 cells disposed in 5 tiers).
l—pvt	*l—pvt + pco*
l′—pco	*l_1′ — ½ phy + icc*
m—phy + icc + iec	*l_2′ — ½ phy + iec + co*
n—co	*m—* } *s*
n′—s	*ci—* }

IV. Fourth Cell Generation.

S. media (Embryo of 20 cells disposed in 6 tiers).	*P. Læflingiæ* (Embryo of 11 cells disposed in 7 tiers).
l—pvt	*l—pvt + pco*
l′—pco	*l_1′ — ½ phy + icc*
m—phy + icc + iec	*l_2′ — ½ phy + iec + co*
n—co	*m—(2-tiered)—* } *s*
o— } *s*	*ci—(2-tiered)—* }
p— }	

V. Fifth Cell Generation: (In *P. Læflingiæ* only). Embryo of 14 cells disposed in 8 tiers.

l—pvt + pco
l_1′ — ½ phy + icc
l_3′ — ½ phy + iec
l_4′ —co
m—(2-tiered)— } *s*
ci—(2-tiered)— }

In some members of Caryophyllaceæ the suspensor is massive or biseriate. In *P. Læflingiæ*, however, it is uniseriate (though in some cases a cell is found to have divided longitudinally) and derived entirely from the primary basal cell. An intermediate type as mentioned by Schnarf (1931) is found in *Sagina procumbens* (Souèges, 1924), *Lychnis alba* (Devine, 1950), *Stellaria media* and in the genera *Melandrium*, *Cerastium*, *Silene*, *Agrostemma*, etc. Here the basal cell is bladder-like and prominently haustorial in nature. The other suspensor cells in *S. media* which vary from one to four are derived from the primary embryonal cell and are found to be normal in structure. A weakly developed haustorial basal cell has been found also in *P. tetraphyllum* by Rocén (1927).

Summary.

The present paper deals with the development of the flower, pollen, embryo-sac, embryo and seed in *Stellaria media* and *Polycarpon Læflingiæ*.

1. The organogeny of the flowers is normal, except in *S. media* where the stamens arise prior to the petals. In *P. Læflingiæ*, the condition of the axile placentation is retained even in the young fruits.

2. The tapetal cells in the anthers are binucleate and are of the secretary type.

3. The haploid number of chromosomes is 14 in *S. media* and 18 in *P. Læflingiæ*. Cytokinesis takes place by furrowing. The pollen grains are spherical at maturity. In *P. Læflingiæ*, they are deeply furrowed in the intermediate stages of development. The pollen grains are rich in starch and are shed in the 3-nucleate condition.

4. The ovules are hemianatropous and bitegmic. The micropyle is formed only by the inner integument. The presence of a nucellar cap over the embryo-sac is a characteristic feature. The nucellus is massive and the integuments are two cells thick.

5. The primary archesporium of the ovule is generally multicellular and hypodermal in origin, but in *S. media* a single archesporial cell functions as the megaspore-mother cell after cutting a parietal cell. In *P. Læflingiæ*, however, several mother cells may be formed but only the median one functions.

6. In *S. media*, a linear tetrad of megaspores is formed and the chalazal megaspore functions to give rise to a 'Normal type' of embryo-sac. In *P. Læflingiæ*, however, generally a linear row of two chalazal megaspores and one micropylar dyad cell is formed of which the chalazal megaspore functions. In a few cases normal linear tetrads of megaspores have also been observed of which the micropylar one functions.

7. Fertilization is normal and porogamous.

8. The division of the primary endosperm nucleus takes place before that of the oospore. The endosperm is of the 'Nuclear type' and the nature of cell-formation of the endosperm tissue conforms to the 'Helosperma type' in *S. media* and 'Silene type' in *P. Læflingiæ*.

9. The nature of development of the embryo is different in the two plants investigated. The development of the embryo in *S. media* is after 'Caryophyllad type', but in *P. Læflingiæ* it is after 'Solanad type'. In *S. media* the primary suspensor cell becomes bladder-like and haustorial, while it is not so in *P. Læflingiæ*. In the latter, polyembryony has been noted in one instance.

10. The seed contains a large amount of perisperm, and a trace of endosperm at the micropylar end of *S. media* only. The testa is two-layered of which the outer one is characteristically thickened and modified. In *P. Læflingiæ* the tegmen is absent, while in *S. media* it is one-layered.

In conclusion, I desire to express my sincerest thanks and gratitude to Dr. I. Banerji under whose guidance and care this work was carried out. I am also very much indebted to Principal J. C. Sen Gupta and Prof. P. Maheshwari who helped me with literature.

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THE OPTICAL PRINCIPLES OF THE LOW ANGLE SCATTERING OF X-RAYS.

By N. N. GUPTA, *Department of X-rays and Magnetism, Indian Association for the Cultivation of Science, Jadavpur, Calcutta 32.*

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INTRODUCTION.

From the optical principles of X-ray diffraction, the intensity of the diffracted beam in any direction represented by a point (ξ, η, ζ) in the reciprocal space is given by the equation (1913)

$$I_0(\xi, \eta, \zeta) = \frac{\sin^2(\pi N_1 \xi)}{\sin^2(\pi\xi)} \cdot \frac{\sin^2(\pi N_2 \eta)}{\sin^2(\pi\eta)} \cdot \frac{\sin^2(\pi N_3 \zeta)}{\sin^2(\pi\zeta)}$$

where, ξ, η, ζ are the components of the radius vector of the point from the origin parallel to the three reciprocal axes. This is not zero just outside the reciprocal lattice points, but has appreciable values throughout a continuous three dimensional envelope surrounding each reciprocal lattice points. The pattern and the volume of this envelope depends on the external shape and the size of the crystal particle, the thermal motion of the molecules and the lattice defects being neglected. The smaller the size of the particle the greater is the volume of the envelope. Later on Laue (1936) calculated a relation between intensity and the crystal form factor which represents the amplitude scattered under given conditions by a continuous volume distribution of scattering matter having the same boundaries as the crystal and does not depend upon the type of the lattice upon which the crystal is built. Following is the relation :—

$$I_0(\xi, \eta, \zeta) = \left(\frac{\pi\xi}{\sin \pi\xi} \cdot \frac{\pi\eta}{\sin \pi\eta} \cdot \frac{\pi\zeta}{\sin \pi\zeta}\right) \left|E(\rho)\right|^2$$

where, $E(\rho)$ is the crystal form factor, ρ being the vector distance of any point ξ, η, ζ from its nearest reciprocal lattice point in the reciprocal space. By an extension of his calculation he showed that the intensity distributions have projections perpendicular to the binding faces of the crystal. The larger the area of the face the stronger and sharper are the projections. These were termed as 'Intensity Spikes' by Laue. The same calculation was further extended over the lines of all the edges surrounding the face of the crystal and it was further seen that the intensity distribution has subsidiary spikes in the directions perpendicular to surrounding edges. One entire intensity distribution pattern consists of a number of primary and subsidiary intensity spikes.

This knowledge about intensity patterns from Laue's calculation would very conveniently help to determine the shape and size of the submicroscopic particles of crystals but owing to the following difficulties it was not possible :—

(1) To take X-ray diffraction photograph of a single submicroscopic particle is not practically possible.

(2) On the other hand, the resultant intensity distribution pattern of a large number of submicroscopic particles consists of many concentric

spheres, traced out by the revolution of the reciprocal lattice points, with its surrounding system of intensity pattern, about the origin of the reciprocal lattice, as the centre of the sphere. The portion of any such spheres intersected by the sphere of reflection defines the cone of diffraction maxima and consequently, there appear only a broadening of the Debye-Scherrer lines in the photographic plate. Therefore, the only thing that is left is to observe the change in intensity along the angular breadth of the lines. Thus a relationship has been deduced by Laue (1926) and Scherrer (1920) between the breadth of the Debye-Scherrer lines as defined by them and particle size for particles of parallelopiped shapes and cubic systems.

It has been shown by Guinier (1939) that the shape and size of particles can be determined from low angle scattering also as this may be regarded as a broadening around the diffracted ray of index (000). In fact, the method of low angle scattering is more convenient than Laue's method as the former depends only on the shape and size of the particles and independent of their internal structure.

That the methods of physical optics are applicable to X-ray scattering at small angles was first pointed out by Raman and Ramanathan (1923) in the case of liquids since for small angle scattering the phase differences between rays scattered from neighbouring atoms or molecules are negligible and the internal discrete structure may be overlooked. The same arguments will naturally be applicable to the solid state and so for small angle scattering the fine structure of the scatterer is immaterial, only the sizes and shapes of the crystallites are to be taken into considerations. Guinier (1939) also arrived at the same conclusion after a very detailed and complex analysis. The study of low angle scattering has therefore a very wide scope of application in the field of determination of the size and shape of particles as it does not matter whether they are crystalline, amorphous or colloidal. In view of the importance of low angle scattering and since the optical principles are applicable to this problem we propose in this paper to investigate it as a problem of Fraunhofer diffraction. As the mathematics is considerably simplified in that way, it is expected that the scope of applicability of the method of low angle scattering may be extended to more and more complicated cases. In the present discussions we shall restrict ourselves to the cases of (1) sphere, (2) plates.

Physical Principles.

A pencil of X-rays has been considered as a parallel pencil of optical rays and the particles of any shape as continuously uniform aggregations of indefinitely small scattering units among the rays scattered from which there is no appreciable phase difference. The scattering medium as a whole is also considered to be transparent to the rays.

The maximum phase difference between the rays scattered by two neighbouring atoms is given by

$$\frac{2\pi}{\lambda} d \sin \epsilon \quad .. \quad .. \quad .. \quad .. \quad .. \quad (1)$$

where, d is the distance between the two neighbouring atoms and ϵ the angle of scattering. Since d and λ are of the same order of magnitude this phase difference becomes negligible when ϵ is small.

Now, if the entire medium be imagined to be an aggregation of indefinitely small volumes within which the phase change from the scatterers will be accordingly small, there is fair justification in considering the medium as optically continuous within those small volumes for all problems of coherent scattering. Thus we are

justified in considering our problem as one of a three dimensional Fraunhofer diffraction.

Three Dimensional Fraunhofer Scattering Phenomena.

(*General Treatment.*)

Proceeding in the usual way of investigating the Fraunhofer class of diffraction (*vide* Drude: *Theory of Optics*, pp. 185 and 214) we may put

$$I = A^2(C^2+S^2) \quad .. \quad .. \quad .. \quad .. \quad .. \quad (2)$$

where, $C = \int \cos(\lambda x+\mu y+\nu z)\, d\tau,$

$$S = \int \sin(\lambda x+\mu y+\nu z)\, d\tau,$$

and $$\lambda=\frac{2\pi}{\lambda_w}\left(\alpha_1+\alpha_0\right), \qquad \mu=\frac{2\pi}{\lambda_w}\left(\beta_1+\beta_0\right), \qquad \nu=\frac{2\pi}{\lambda_w}\left(\gamma_1+\gamma_0\right)$$

λ_w being the wavelength of radiation,
$\alpha_1, \beta_1, \gamma_1$, being the direction cosines of the incident ray,
and $\alpha_0, \beta_0, \gamma_0$, being the direction cosines of the scattered ray, and A is given by

$$I_0 = A^2\tau^2 \quad .. \quad .. \quad .. \quad .. \quad .. \quad (3)$$

where, I_0 is the incident intensity and τ the volume of the scatterer. Therefore, the expression of intensity for three dimensional Fraunhofer scattering becomes—

$$\frac{I}{I_0}=\frac{1}{\tau^2}\left(C^2+S^2\right) \quad .. \quad .. \quad .. \quad .. \quad (4)$$

Case of Spherical Particles.

(*Non-Absorbing.*)

Preliminary Assumptions.

For the sake of simplicity following assumptions have been made :—

(1) The incident ray is parallel and opposite to the direction of z-axis.
(2) The origin has been taken at the centre of the sphere and spherical polar system of co-ordinates has been introduced.

Then, in spherical polar system the following relationship holds—

$$\text{(i)} \begin{cases} \alpha_1 = \beta_1 = 0, & \gamma_1 = \cos\pi \\ \alpha_0 = \sin\epsilon\cos\eta, & \beta_0 = \sin\epsilon\sin\eta, \text{ and } \gamma_0 = \cos\epsilon \end{cases}$$

where, $\alpha_1, \beta_1, \gamma_1$ = direction cosine of the incident ray.
$\alpha_0, \beta_0, \gamma_0$ = direction cosine of the scattered ray.
ϵ = the angle which the scattered ray makes with the z-axis, i.e. the angle of scattering.
η = the angle which the projection of the scattered ray on the xy-plane makes with the x-axis.

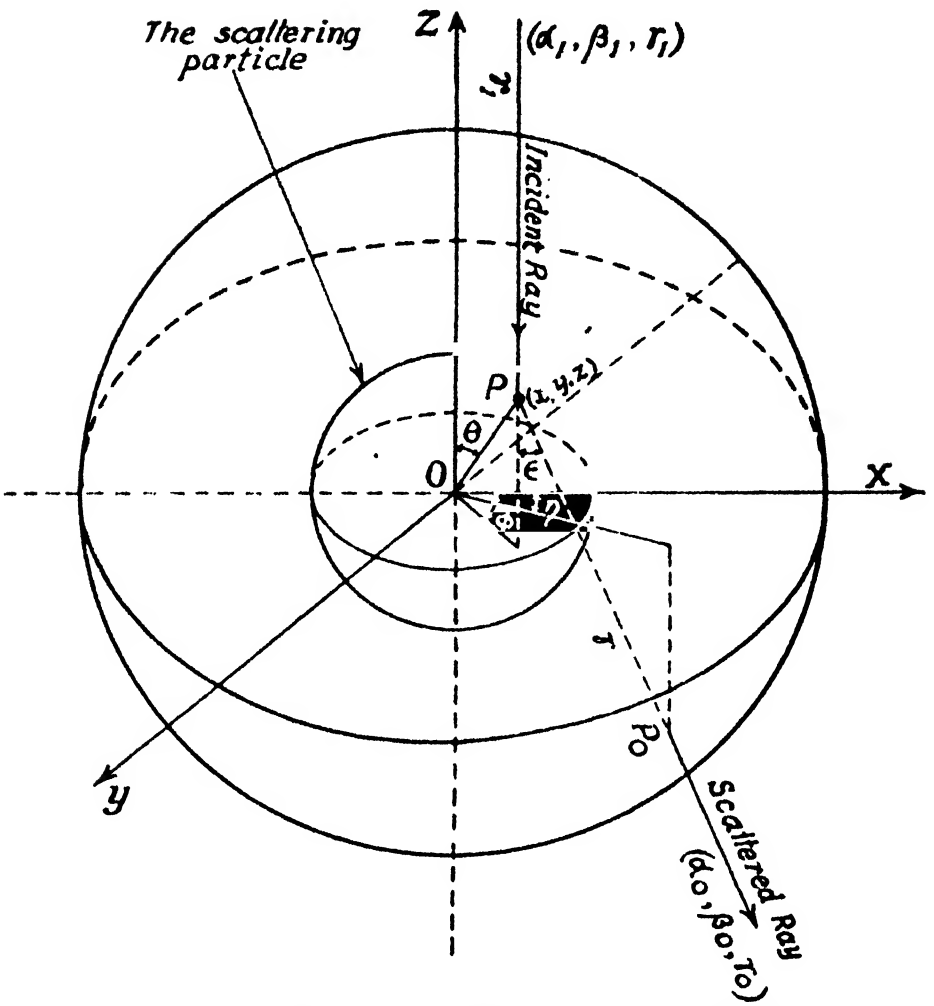

Fig. 1. Case of Spherical particle.

$$\text{(ii)}\quad \begin{cases} \lambda = \dfrac{2\pi}{\lambda_w}\sin\epsilon\cos\eta = p\cos\eta \\ \mu = \dfrac{2\pi}{\lambda_w}\sin\epsilon\sin\eta = p\sin\eta \\ \qquad\qquad \text{where } p = \dfrac{2\pi}{\lambda_w}\sin\epsilon = \dfrac{2\pi}{\lambda_w}\epsilon \\ \nu = \dfrac{2\pi}{\lambda_w}(\cos\pi + \cos\epsilon) \\ \quad = \dfrac{2\pi}{\lambda_w}(-1+1) \\ \quad = 0^*. \end{cases}$$

* In the case of graphite irradiated by copper K_α radiation $\epsilon = 6'$, $\cos 6' = 0{\cdot}99999$. Therefore $\nu = -0{\cdot}00001 \simeq 0$.

(iii) In the intensity equation (4) which is given by

$$\frac{I}{I_0}=\frac{1}{r^2}(C^2+S^2),\ S=0.$$

Then (4) becomes—

$$\frac{I}{I_0}=\frac{C^2}{r^2} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (5)$$

(iv)
$$x = r\sin\theta\cos\phi$$
$$y = r\sin\theta\sin\phi$$
$$z = r\cos\theta$$
$$d\tau = r^2\sin\theta\, dr\, d\theta\, d\phi$$

(v)
$$C=\int_0^{2\pi}\int_0^{\pi}\int_0^{R} r^2\sin\theta\, dr\, d\theta\, d\phi\cos\left[\lambda\sin\theta\cos\phi+\mu\sin\theta\sin\phi\right]$$
$$=\int_0^{2\pi}\int_0^{\pi}\int_0^{R} r^2\sin\theta\, dr\, d\theta\, d\phi\cos\left[rp\sin\theta\cos\phi'\right] \quad \text{where } \phi'=(\phi-\eta)$$
$$=\int_0^{R}\int_0^{\pi} r^2\sin\theta\, dr\, d\theta\int_{-\eta}^{2\pi-\eta}\cos\left[rp\sin\theta\cos\phi'\right]d\phi'$$

THE INTEGRAL IN ϕ'.

$$=\int_{-\eta}^{2\pi-\eta}\cos\left[rp\sin\theta\cos\phi'\right]d\phi'$$
$$=\text{Real part in}\int_{-\eta}^{2\pi-\eta} e^{i[rp\sin\theta\cos\phi']}d\phi' \quad .. \quad .. \quad .. \quad .. \quad (6)$$
$$=\int_{-\eta}^{2\pi-\eta} e^{i[rp\sin\theta\cos\phi']}d\phi'$$
$$=\int_{-\eta}^{2\pi-\eta}\left[1+irp\sin\theta\cos\phi'+\frac{(irp\sin\theta\cos\phi')^2}{2!}+\ldots.\right.$$
$$\left.+\ldots.+\frac{(irp\sin\theta\cos\phi')^{2m}}{2m!}+\ldots.\right]d\phi'$$

Now,
$$\int_{-\eta}^{2\pi-\eta}\cos\phi'\,d\phi'=0, \quad \int_{-\eta}^{2\pi-\eta}\cos^2\phi'\,d\phi'=\frac{2\pi}{2}$$
$$\int_{-\eta}^{2\pi-\eta}\cos^3\phi'\,d\phi'=0, \quad \int_{-\eta}^{2\pi-\eta}\cos^4\phi'\,d\phi'=2\pi\cdot\tfrac{3}{8}$$
. . . .

The odd powers cancel and consequently.

$$\int_{-\eta}^{2\pi-\eta}\cos^{2m}\phi'\,d\phi'=\frac{(2m-1)(2m-3)\ldots.3\cdot1}{2m(2m-2)\ldots.4\cdot2}2\pi$$

Therefore, the integral in ϕ', i.e. the real part in (6)

$$= 2\pi\left[1-\frac{r^2p^2\sin^2\theta}{2!}\cdot\frac{1}{2}+\frac{r^4p^4\sin^4\theta}{4!}\cdot\frac{3}{8}+\ldots\ldots-\ldots\ldots\right.$$

$$\left.(-1)^m\frac{(2m-1)(2m-3)\ldots\ldots3.1}{2m(2m-2)\ldots\ldots4.2}\cdot\frac{p^{2m}r^{2m}\sin^{2m}\theta}{2m!}+\ldots\ldots\right]$$

THE INTEGRAL IN θ.

$$=\sum_{m=0}^{m=\infty}(-1)^m\frac{(2m-1)(2m-3)\ldots\ldots3.1}{2m(2m-2)\ldots\ldots4.2}\cdot\frac{2\pi}{2m!}p^{2m}r^{2m}\int_0^{\pi}\sin^{2m+1}\theta\,d\theta$$

$$=4\pi\sum_{m=0}^{m=\infty}(-1)^m\frac{(2m-1)(2m-3)\ldots\ldots3.1}{2m(2m-2)\ldots\ldots4.2}\cdot\frac{1}{(2m)!}$$

$$\times\frac{2m(2m-2)\ldots\ldots4.2}{(2m+1)(2m-1)\ldots\ldots5.3}\times p^{2m}r^{2m}$$

THE INTEGRAL IN r.

$$=4\pi\sum_{m=0}^{m=\infty}(-1)^m\frac{(2m-1)(2m-3)\ldots\ldots3.1}{2m(2m-2)\ldots\ldots4.2}\cdot\frac{1}{(2m)!}$$

$$\times\frac{2m(2m-2)\ldots\ldots4.2}{(2m+1)(2m-1)\ldots\ldots5.3}\cdot p^{2m}\int_0^R r^{2m+2}\,dr$$

$$=4\pi\sum_{m=0}^{m=\infty}(-1)^m\frac{p^{2m}}{(2m+1)!}\cdot\frac{R^{2m+3}}{(2m+3)}$$

$$=\tfrac{4}{3}\pi R^3\sum_{m=0}^{m=\infty}(-1)^m\frac{3(2m+2)}{(2m+3)!}p^{2m}R^{2m}$$

$$\tfrac{4}{3}\pi R^3\sum_{m=0}^{m=\infty}(-1)^m\frac{3(2m+2)}{(2m+3)!}u^{2m}$$

where $pR=u$, R being the particle size. .. .. (7)

Therefore,

$$C=\tau\sum_{m=0}^{m=\infty}(-1)^m\frac{3(2m+2)}{(2m+3)!}u^{2m}$$

$$=\tau\left[1-\frac{u^2}{2.5}+\frac{u^4}{2.4.5.7}-\ldots\ldots\right]$$

From (5)

$$\frac{I}{I_0}=\left[1-\frac{u^2}{5}+u^4\left(\frac{1}{140}+\frac{1}{100}\right)-\ldots\ldots\right]$$

$$=\left[1-\frac{u^2}{5}+\left(\frac{u^2}{5}\right)^2\frac{1}{2!}\cdot\frac{6}{7}-\ldots\ldots\right] \quad .. \quad .. \quad .. \quad .. \quad (8)$$

By making particle size sufficiently small* in (8) we can write—

$$I = I_0 e^{-\frac{u^2}{5}} \text{ (approx.)} \quad .. \quad .. \quad (9)$$

$$\log I = -\frac{4\pi^2}{5\lambda^2} R^2 \epsilon^2 \log e + \log I_0 \quad .. \quad (10)$$

} Guinier's formula.

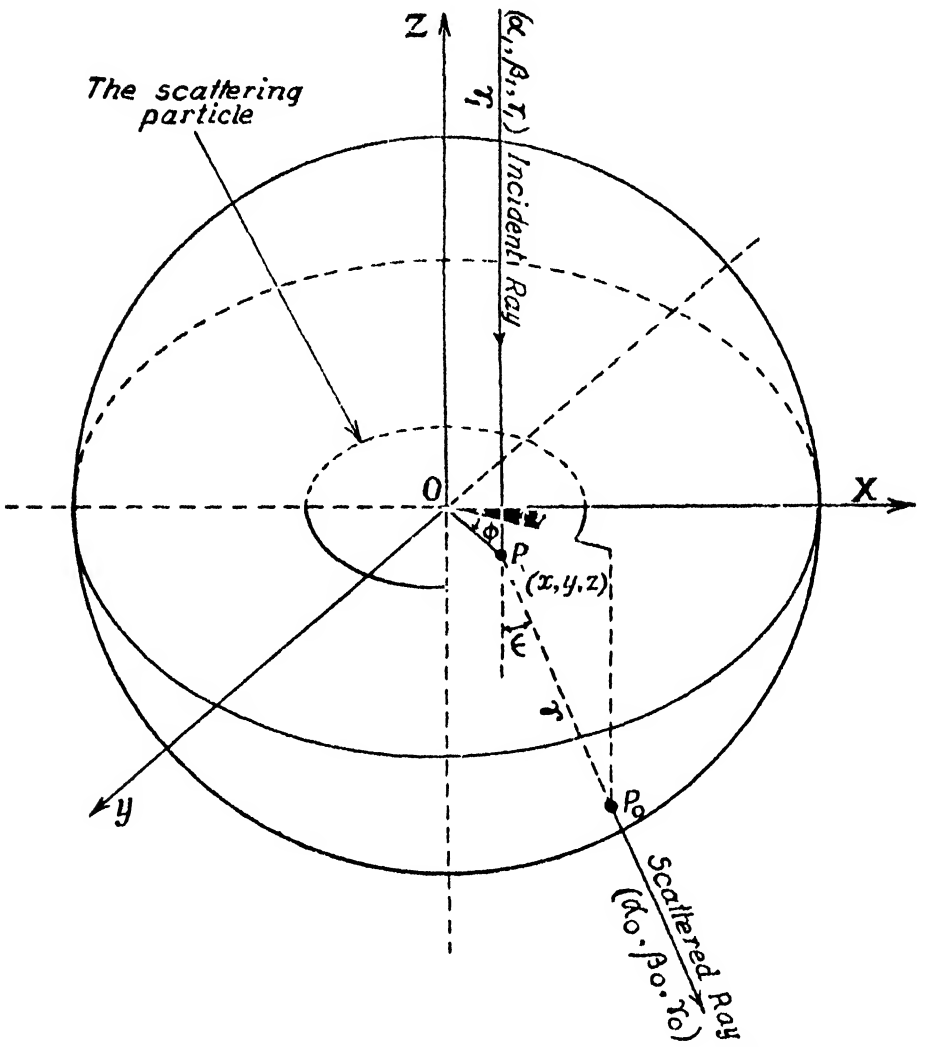

Fig. 2. Case of plate shaped particle.

* When, $R = 100$ Å, $\epsilon = 6' = 17 \times 10^{-4}$ radians λ_ω 1·5 Å for copper K_α radiation, we get—

$$u = \frac{2\pi}{\lambda_\omega} \epsilon R = \frac{10}{15} \text{ (approx.)}$$

$$\left(\frac{u^2}{5}\right)^2 \cdot \frac{1}{21} = \frac{1}{110} \text{ (approx.)}$$

$$\frac{1}{7} \cdot \left(\frac{u^2}{5}\right)^2 \frac{1}{21} = \frac{1}{800} \text{ (approx.)}$$

Therefore, for particles of magnitude 100 Å, we are making an error of 0·12 per cent in coming from (8) to (9). For particles of much lower dimensions the error is much smaller.

Plate Shaped Particles.

(*Non-Absorbing.*)

Preliminary Assumptions:

(1) A circular plate has been taken into consideration.
(2) The origin has been taken at the centre of the circle and its plane coincides with the xy-plane.
(3) The incident ray is parallel and opposite to z-axis.

Then taking relation (i) of the case of spherical particles and previous others, following relations are obtained

$$C = \int_0^{2\pi}\int_0^R r\,d\phi\,dr\cos\left[r\{\lambda\cos\phi+\mu\sin\phi\}\right]$$

$$= \int_0^{2\pi}\int_0^R r\,d\phi\,dr\cos\left[rp\cos\phi'\right]$$

where,

$$\lambda = \frac{2\pi}{\lambda_w}\sin\epsilon\cos\eta = p\cos\eta,$$

$$\mu = \frac{2\pi}{\lambda_w}\sin\epsilon\sin\eta = p\sin\eta,$$

$$\phi' = \phi-\eta.$$

Integral in ϕ'.

$$= \int_{-\eta}^{2\pi-\eta}\cos\left[rp\cos\phi'\right]d\phi'$$

$$= \text{Real part in}\int_{-\eta}^{2\pi-\eta} e^{irp\cos\phi'}\,d\phi'.$$

$$\int_{-\eta}^{2\pi-\eta} e^{irp\cos\phi'}\,d\phi' = \int_{-\eta}^{2\pi-\eta}\left[1+irp\cos\phi'+\frac{(irp\cos\phi')^2}{2!}+\ldots.\right.$$

$$\left.+\ldots.+\frac{(irp\cos\phi')^{2m}}{(2m)!}+\ldots.\right]d\phi'.$$

As before, all the odd powers cancel after integration and only the even powers remain which contribute to real parts.

Therefore, the integral in ϕ'

$$= 2\pi\sum_{m=0}^{m=\infty}(-1)^m\frac{(2m-1)(2m-3)\ldots.3.1}{2m(2m-2)\ldots.4.2}\cdot\frac{1}{(2m)!}\cdot r^{2m}p^{2m}.$$

INTEGRAL IN r.

$$= 2\pi \sum_{m=0}^{m=\infty} (-1)^m \frac{(2m-1)(2m-3) \cdot \cdot \cdot \cdot 3.1}{2m(2m-2) \cdot \cdot \cdot \cdot 4.2} \cdot \frac{1}{(2m)!} p^{2m} \int_0^R r^{2m+1} dr$$

$$= 2\pi \sum_{m=0}^{m=\infty} (-1)^m \frac{(2m-1)(2m-3) \cdot \cdot \cdot \cdot 3.1}{2m(2m-2) \cdot \cdot \cdot \cdot 4.2} \cdot \frac{1}{(2m)!} \frac{p^{2m} R^{2m+2}}{(2m+2)}$$

$$C = 2\pi R^2 \sum_{m=0}^{m=\infty} (-1)^m \frac{1}{2^{2m+1}(m+1)!\, m!} u^{2m}$$

$$= 2\pi R^2 \left[\frac{1}{2} - \frac{u^2}{2^2.4} + \frac{u^4}{2^2.4^2.6} - \cdot \cdot \cdot \cdot \right]$$

Therefore, from (5)

$$\frac{I}{I_0} = 1 - \frac{u^2}{4} + \frac{1}{2!}\left(\frac{u^2}{4}\right)^2 \frac{5}{6} - \cdot \cdot \cdot \cdot$$

$$= e^{-\frac{u^2}{4}} \text{ (approx.)} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (11)$$

Approximation in (11) is done by making particle size sufficiently small as explained in the case of spherical particles.

$$\log I = -\frac{\pi^2}{\lambda^2} \epsilon^2 R^2 \log e + \log I_0, \quad .. \quad .. \quad .. \quad (12)$$

where $u = pR = \frac{2\pi}{\lambda} \epsilon R$ as before.

RESULTS.

The theoretical equations (10) and (12) are for a single particle. But in actual practice we deal with a number of particles possibly with various gradations in size. So, what we get experimentally is their average particle size.

If n be the number of particles and $\bar{R}$ their average size, then equations (10) and (12) become,

$$\log I = -\frac{4\pi^2}{5\lambda_w^2} \epsilon^2 \bar{R}^2 \log e - \log n + \log I_0 \quad .. \quad .. \quad (13)$$

$$\log I = -\frac{\pi^2}{\lambda_w^2} \epsilon^2 \bar{R}^2 \log e - \log n + \log I_0 \quad .. \quad .. \quad .. \quad (14)$$

respectively. The graphs of equations (13) and (14) become straight lines having slopes—

$$-\frac{4\pi^2 \bar{R}^2}{5\lambda_w} \log e \text{ and } -\frac{\pi^2}{\lambda_w^2} \bar{R}^2 \log e.$$

From the slope it is easy to calculate the particle size.

The author is grateful to Prof. K. Banerjee for his kind interest and advice in the work.

Abstract.

Laue calculated the shape of the intensity pattern corresponding to the shape of crystalline particles. But that was not practically useful for determining the shape of submicroscopic particles. Moreover, Laue and Scherrer's formula of particle size are only applicable for particles with rectangular parallelopiped shape and cubic crystals. X-ray low angle scattering phenomena is universally useful for determining the shape and size of submicroscopic particles of crystals, liquids and amorphous substances. By applying optical principles, the formula for particle size and intensity of X-ray low angle scattering has been obtained.

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ON THE LUMINESCENCE OF SOME ORGANIC PHOSPHORS UNDER X-RAYS AND CATHODE RAYS.

By H. N. Bose, J. Sharma, *and* A. Chatterjee, *Khaira Laboratory of Physics, University College of Science and Technology, Calcutta.*

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Introduction

The visible part of the luminescence spectra of anthracene, naphthalene, phenanthrene, triphenylmethane and diphenyl, under X-ray excitation were measured and reported earlier (Bose, 1945, 1948); the measurements have now been extended to the near ultraviolet region and in the present paper are reported the luminescence spectra of these samples under X-rays as well as cathode rays at room temperature (300°K.) and at liquid oxygen temperature. The long period decay exhibited by some of these compounds under cathode rays have been studied and their thermoluminescence curves measured.

The samples were purified by vacuum distillation and their luminescence spectra under ultraviolet excitation measured for the sake of comparison; as the same specimens have been used in all cases, the effect of impurity if any, is the same in different cases.

Experimental Method.

The experimental arrangement for X-ray excitation is essentially the same as that reported by Bose (1945, 1948); for low temperature work, the substance is rubbed in thin layer on the flattened surface of a tube containing liquid oxygen and it is enclosed in a larger tube which can be evacuated. The open end of the inner tube projected outside and is the inlet for liquid oxygen. The outer tube has two windows covered with aluminium foil and quartz plate respectively for introducing the X-ray beam and for the transmission of luminescence light (Chatterjee, 1950). X-rays from a copper target at 40 kV. with 10 m.a. were generally used for excitation.

In the case of cathode ray excitation, the cathode ray tube described by Bose and Sharma (1950) could be used for these samples also. The phosphors were excited by electrons of energy 2–5 kV. and even less where possible. Evaporation of the specimens is greatly reduced at low temperature and the stability of proper discharge condition can be realised by maintaining a high speed of vacuum. Even if the sample evaporates completely, fresh samples can be deposited on the cooled surface of the sample holder by sublimation of specimen introduced into the vacuum chamber. The whole system (cathode ray tube together with the suction line) should be thoroughly cleansed before working with separate phosphors. The measurements on decay and thermoluminescence of some of these organic compounds have been carried out with the help of photomultiplier tubes; the details of the experimental arrangements for recording the decay and glow curves have been described elsewhere by Bose and Sharma ('On the long period afterglow of alkali halides under cathode rays'—to be published shortly).

Results and Discussions.

The luminescence spectra of these compounds consist of a number of bands which become quite sharp at liquid oxygen temperature. It has been found that the luminescence spectra under X-rays or cathode rays are not always the same as those exhibited under ultraviolet excitation; in general, a larger number of bands are emitted in the former case. The spectrum emitted under X-ray and cathode ray excitation is, however, identical in all the cases studied except for naphthalene. The phosphor specimens, of course, get spoilt by cathode ray irradiation for more than few minutes. Hence the luminescence spectra under cathode rays were taken with a comparatively wider slit. As a consequence, the closely spaced weaker components which could be measured from X-ray luminescence spectrum were, in some cases, lost due to overlapping in the case of cathode ray luminescence.

Under X-ray and cathode ray excitation most of these compounds show at liquid oxygen temperature a measurable afterglow which is most remarkable for triphenyl methane and can be seen even at room temperature in this case. Under cathode rays, the intensity as well as the persistence of afterglow is very prominent. The measurement of decay and glow curves have thus been carried out for some of these compounds under cathode ray excitation only. In recording the glow curves for these substances, it has been observed that as heating proceeds with consequent evaporation of the substance, the discharge tube is gradually filled up with its vapour, and sudden flashes of light are frequently emitted by the gaseous mass. This is evidently due to the fact that emission by collision processes occurs from the excited molecules which have passed into the gaseous state; this is perhaps one of the reasons why the glow peak which is a measure of the stored up energy of the phosphors, is so shallow in the case of organic phosphors. It has been verified that thermoluminescence exhibited by these compounds is no fortuitous effect. The sample after being excited at liquid oxygen temperature, may be quickly taken out of the discharge tube, and increased intensity of emission on simple touching or pouring warm water can be easily observed in a dark room.

Naphthalene:

The luminescence spectrum of naphthalene under X-ray excitation consists of a number of diffuse bands extending throughout the visible region together with a group of closely spaced sharp bands in the region 330–450 mμ. The ultraviolet group of bands is very intense and can be recorded very easily while the comparatively weaker emission in the visible region can be obtained only with long exposure. Under ultraviolet excitation naphthalene emits only the group of bands in 330–450 mμ region. At liquid oxygen temperature, the visible part of the emission is still more reduced in intensity and the u.v. band system is usually obtained by X-ray excitation; the band system shifts towards the shorter wavelength side and becomes sharper at low temperature. The ultraviolet band pattern is absent in the luminescence spectrum excited by cathode rays; because of the low temperature, the emission bands in the visible region attain linelike sharpness and are resolved into several components.

The ultraviolet bands of naphthalene excited by X-rays show an almost mirror image symmetry with the strong 260 mμ absorption of solid naphthalene terminating at 295 mμ. Thus these two systems seem to belong to the same group of electronic transitions, $^1A_{1g} \rightleftarrows {}^1B_{2u}$. Seshan (1936) from his absorption data has assigned vibration frequencies of 260 cm.$^{-1}$ and 460 cm.$^{-1}$ for the ground and excited states of solid naphthalene respectively with 327 mμ (= 30580 cm.$^{-1}$) as the longest wavelength limit of (260 mμ) absorption bands of solid naphthalene. The mean vibration frequencies of 220 cm.$^{-1}$ and 470 cm.$^{-1}$ for the ground and excited state respectively are obtained from the ultraviolet fluorescence bands of naphthalene.

The emission bands in the visible region cannot be correlated with $^1B_{2u} \rightarrow {}^1A_{1g}$ transition and seems to have a separate origin. There is nothing to indicate whether or not the higher excited states $B_{1u} \rightarrow A_{1g}$ or $B_{3g} \rightarrow A_{1g}$ (forbidden) are involved in the emission process. This also does not explain the low intensity of visible emission under X-rays or the absence of u.v. bands under cathode rays, although luminescence in both cases takes place through identical processes, i.e., through the intermediary of secondary electrons. It is possible that naphthalene is unstable under cathode rays and the unstable products or their recombination are responsible for these bands. In the case of cathode rays, electrons are absorbed within a thin layer and so the effect is greater. That similar results are not obtained with other phosphors studied so far is not quite clear.

TABLE I.

Luminescence spectrum of Naphthalene.

Under X-ray excitation.				Under cathode ray excitation	
At 300°K.		At 90°K.		At 90°K.	
Wavelength in mμ	Δν in cm.$^{-1}$	Wavelength in mμ	Δν in cm.$^{-1}$	Wavelength in mμ	Δν in cm.$^{-1}$
330·0		327·5		539·0	
	320		190		370
333·5		329·0		550·0	
	515		235		100
339·3		332·1		553·5	
	460		435		160
344·7		337·0		558·0	
	355		220		190
349·0		339·5		564·0	
	195		300		130
351·5		343·0		568·5	
	320		560		150
355·4		349·7		573·5	
	430		345		120
360·9		354·0		577·0	
	655		215		640
369·6		356·7		590·0	
	705		220		380
379·5		359·5		613·0	
	475		265		160
386·5		363·0		619·0	
	255				100
390·3				623·5	
	240				180
394·0				630·5	
	440				100
401·0				634·0	
	580				
410·5(?)					
	1965				
446·5					

Diphenyl:

The measurements of the luminescence spectra of diphenyl under X-rays and cathode rays are given in Table II. Besides these, diphenyl emits a number of

bands in the visible region which were measured by Bose (1948) with a glass spectrograph; these are comparatively weaker and have been omitted in the present measurement. Under the ultraviolet excitation of diphenyl, only four bands are obtained: 430, 409, 391 and 370 mμ. The luminescence spectrum under X-rays and cathode rays is identical except that in the case of cathode ray excitation some of the weaker structures are lost due to overlapping because of greater slit width. The lowering of temperature has no marked effect on the positions of the band maxima, though greater accuracy in the measurement of the band positions can be attained due to the increased intensity and sharpness of the bands at liquid oxygen temperature. As the same samples have been used in different cases, it is to be surmised that additional emission bands of diphenyl under X-rays or cathode rays are due to some changes introduced in the crystal by this method of excitation.

TABLE II.

Luminescence spectrum of Diphenyl.

Under X ray excitation.				Under cathode ray excitation.	
At 300°K.		At 90°K.		At 90°K.	
Wavelength in mμ	$\Delta\nu$ in cm.$^{-1}$	Wavelength in mμ	$\Delta\nu$ in cm.$^{-1}$	Wavelength in mμ	$\Delta\nu$ in cm.$^{-1}$
353·0		351·0		353	
	240		240		320
356·0		354·0		357	
	300		150		390
359·8		355·0		362	
	120		160		740
360·0*		357·9		372	
	670		200		140
362·8*		360·5		374	
	230		250		970
370·8		363·8		388	
	430		420		330
380·1		369·4		393	
	770		120		1050
391·5*		371·0		410	
	180		210		1240
408·8		374·0		432	
	1304		490		1460
431·8		381·0		461·5	
	1330		360		
458·0		393·0			
	730		870		
474·0		407·0			
			390		
		414·4			
			970		
		431·8			
			1340		
		458·3			

Phenanthrene:

The luminescence spectra of phenanthrene are given in Table III. According to Pringsheim (1943), the blue emission of phenanthrene is due to the traces of anthracene contained in it. On comparison with the luminescence spectrum of

TABLE III.

Luminescence spectrum of Phenanthrene.

Under X-ray excitation at 300°K.		Under cathode ray excitation at 90°K.	
Wavelength in mμ	Δν in cm.$^{-1}$	Wavelength in mμ	Δν in cm.$^{-1}$
385·0		385·0	
	330		330
390·0		390·0	
	1190		580
409·0		399·0	
	1270		430
431·5		406·0	
	1390		530
459·0		415·0	
	1470		900
492·0		431·0	
			300
		456·5	

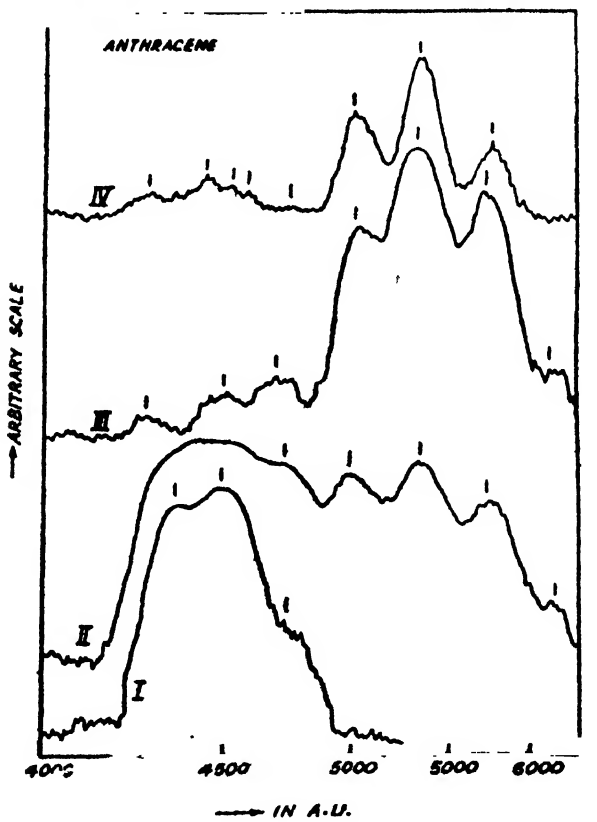


FIG. 1. Microphotometer records (reduced to half size) of various anthracene samples under X-rays. I—Pure. II—Anthracene containing slight traces of Naphthacene. III—Anthracene (Merck). IV—Ordinary anthracene (B.D.H.).

pure anthracene (Table V) it is surmised that the bands 492, 459, 431 are possibly due to anthracene of which the band 459 may be due to the overlapping of the bands 446 and 469 of pure anthracene. At low temperature, under cathode ray excitation the bands due to phenanthrene are resolved into further components.

Phenanthrene emits the same spectrum under X-rays, cathode rays or ultraviolet excitation. This shows that phenanthrene molecules are rather stable under X-rays or cathode rays. The presence of anthracene as impurity does not seem to interfere with the emission of phenanthrene and two systems emit quite independently.

Phenanthrene shows a long period afterglow; the decay of afterglow has been measured for cathode ray excitation at liquid oxygen temperature. The Intensity-time plots are shown in Figs. 2, 3. It is found that the semilog plot is nearly but not exactly a straight line. This non-exponential form of the decay can be due to the presence of two different emitting systems, anthracene and phenanthrene.

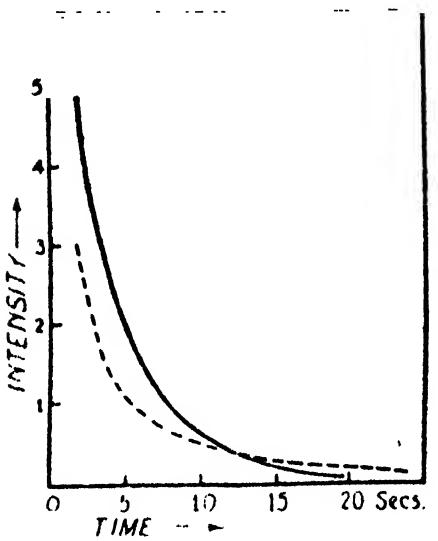


FIG. 2. The after-glow curves of Triphenylmethane (continuous) and Phenanthrene (dotted) with cathode rays excitation at liquid oxygen temperature.

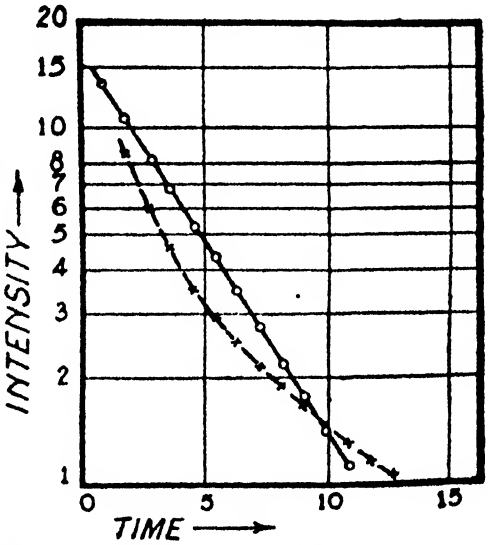


FIG. 3. After-glow curves of Triphenylmethane and Phenanthrene (dotted) plotted on semilog graph paper.

The glow curve of phenanthrene has also been measured; the glow curve (Fig. 4) consists of more than one shallow and extended peaks overlapping with each other, so that the trap depths could not be calculated. The presence of a weak peak observed in the case of anthracene is also suspected in the glow curve.

Triphenylmethane:

A continuous absorption spectrum ranging from 700–230 mμ is reported for triphenylmethane (Seshan, 1936). When excited by ultraviolet rays an almost continuous emission (500–406 approx.) is obtained; weak maxima which nearly agree with the band maxima of the X-ray luminescence spectrum in this region (471, 464, 447, 427 mμ) can be suspected. The luminescence spectra of triphenylmethane under X-ray and cathode ray excitation is given in Table IV. In these cases, the emission consists of a number of discrete bands extending throughout the whole of the visible region. At liquid oxygen temperature, the bands are very

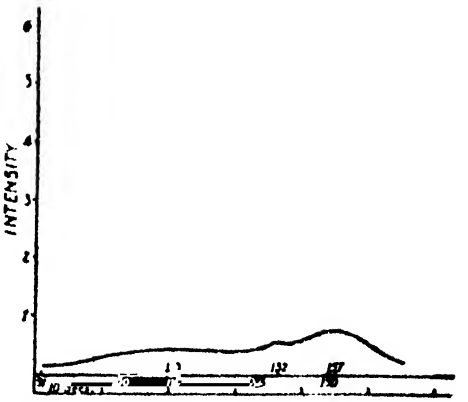


FIG. 4. Thermoluminescence record of Phenanthrene starting at liquid oxygen temperature with cathode rays excitation.

TABLE IV.

Luminescence spectrum of Triphenylmethane.

Under X-ray excitation at 300°K.		Under cathode ray excitation at 90°K.	
Wavelength in mμ	Δν in cm.$^{-1}$	Wavelength in mμ	Δν in cm.$^{-1}$
426·5		427·0	
	1050		1200
446·5		450·0	
	870		430
464·5		459·0	
			2450
		517·0	
			750
		538·0	
			410
		550·0	
			260
		558·0	
			190
		564·0	
			400
		577·0	
			480
		590·0	
			1100
		631·0	

sharp and split up into several components. X-ray luminescence spectrum taken at room temperature, thus consists of diffuse bands which do not agree well with those obtained under cathode rays at liquid oxygen temperature.

Triphenylmethane has a perceptible afterglow under X-rays even at room temperature. At liquid oxygen temperature, under cathode rays, the afterglow increases greatly in intensity and persistence. The long period decay curve is shown in Figs. 2, 3. The semilog plot is a straight line; thus the decay is

exponential. No perceptible difference in the decay curve is obtained for different spectral region.

The glow curve of triphenylmethane under cathode ray excitation has been measured and is shown in Fig. 5; the glow peak with glow temperature at 215°K. is prominent while another peak at about 149°K. is also suspected. Triphenylmethane thus has got at least two meta-stable states.

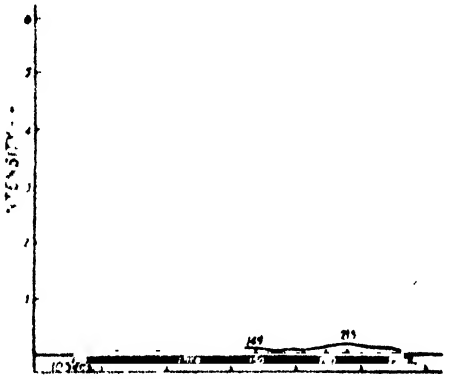


Fig. 5. Thermoluminescence record of Triphenylmethane starting at liquid oxygen temperature with cathode rays excitation.

Anthracene:

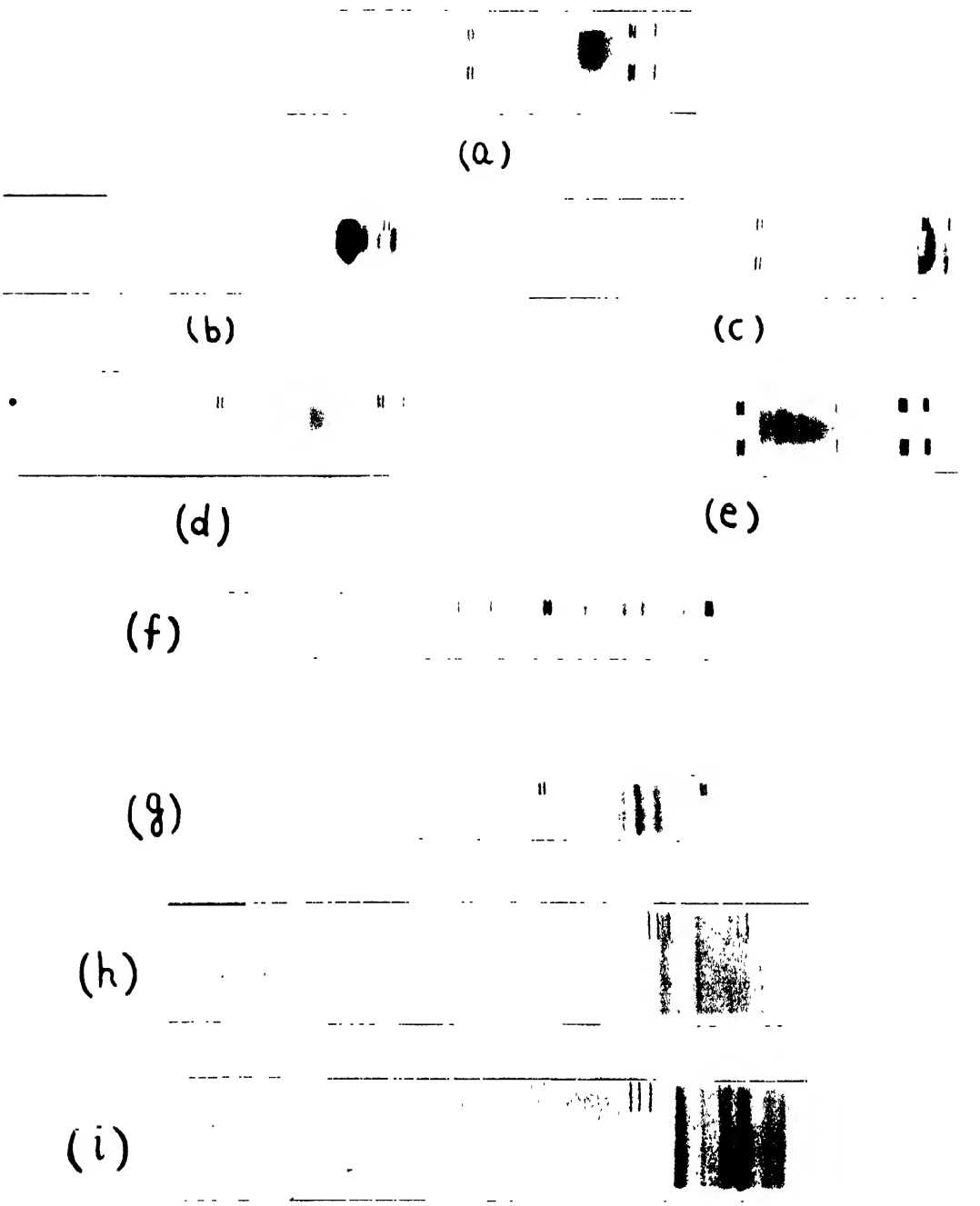
In the present investigation, anthracene, pure, and with different percentages of naphthacene, have been worked with. The measurements are given in Table V.

The luminescence spectrum in all cases is the same under X-rays, cathode rays and u.v. excitation. In anthracene containing 0·2% of naphthacene, bands due to anthracene are very weak and can be obtained only after long exposure. When naphthacene concentration is reduced ($\sim 10^{-5}$), the emissions due to anthracene and naphthacene are of equal intensity. Shifts in the band positions in different cases, of course, take place, and at liquid oxygen temperature under cathode rays the emission bands are considerably sharpened and number of bands is increased.

The mechanism for the transfer of energy from anthracene to naphthacene molecules has been a matter of controversy (Bowen, E. J., and others, 1938, 1944, 1947, 1949 and Ganguly, S. C., 1944 and 1945). Bowen made elaborate measurements on the luminescence of anthracene-naphthacene system and has come to the conclusion that some type of resonance or exciton transfer of electronic energy takes place in this system.

Under X-rays at room temperature the emission spectrum of pure anthracene consists of 492, 469, 446, 431; of these, 446 mμ is very strong and 431 does not seem to be a single band. For anthracene containing naphthacene this band system is greatly reduced in intensity, but the most intense band 446 mμ is affected to a greater extent than any other. According to Ganguly, the absorption spectra of the crystal (containing naphthacene) shows a continuous band shorter than 405 mμ, due to anthracene, and absorption bands at 435, 460 and 491 mμ which are associated with naphthacene. The relatively greater quenching for the shorter wavelength emission bands of anthracene cannot be explained by the process of self absorption unless stronger absorption bands in the corresponding regions are assumed (or continuous absorption).

A very small quantity of purified anthracene could be procured, and so the luminescence spectrum of pure anthracene under cathode rays was not taken (in



Fluorescence spectra of some organic substances. (*a*) Anthracene pure under X-rays; (*b*) Anthracene containing traces of Naphthacene under X-rays, (*c*) Anthracene (Merck) containing greater amount of Naphthacene under X-rays, (*d*) Triphenylmethane under X-rays, (*e*) Naphthalene under X rays at liquid oxygen temperature, (*f*) Diphenyl under cathode rays at liquid oxygen temperature, (*g*) Phenanthrene under cathode rays at −184° C., (*h*) Naphthalene under cathode rays, (*i*) Triphenylmethane under cathode rays at liquid oxygen temperature.

(*a*) and (*i*) have been photographed with glass spectrograph while (*a*) to (*g*) with a quartz spectrograph.

discharge tube the sample is lost by evaporation). At liquid oxygen temperature, as is observed in the luminescence spectra under cathode rays, the emission due to anthracene in anthracene-naphthacene system gains in relative intensity. This seems to indicate that energy transfer is dependent on temperature.

TABLE V.

(1) *Pure anthracene under X-rays at 300°K.*

Wavelength in A.U.	Wave numbers cm.$^{-1}$	$\Delta\nu$ cm.$^{-1}$	Remarks.
4310	23200		The measurements published earlier (Bose, 1947) were made on anthracene containing 0·2% of naphthacene; as a matter of fact, the pure anthracene bands are not at all present there.
		780	
4460	22420		
		1120	
4695	21300		
		990	
4925(?)	20310		

(2) *Anthracene with about ·005% of naphthacene.*

Under X-rays at 300°K. in A.U.	Under cathode rays at 90°K. in A.U.	Remarks.
6520	?	Both anthracene and naphthacene bands are present in almost equal intensity. At low temperature the relative intensities of anthracene bands are increased.
5760	?	
5365	5360	
5010	5240	
4730	5040	
?	4810	
?	4710	
..	4450	
..	4250	
..	4210	

(3) *Anthracene with 0·2% of naphthacene.*

Under X-rays at 300°K. in A.U.	Under cathode rays at 90°K. in A.U.	Remarks.
6320	?	Anthracene bands are very poor in intensity; at low temperature the relative intensity of the anthracene emission is increased.
5755	?	
5360	5370	
5055	5010	
4725	4710	
4485	4559	
4270	4435	
..	4230	
..	4135	

At liquid oxygen temperature anthracene containing naphthacene shows afterglow. The decay of afterglow has been measured with a cathode oscillograph. The decay measurements were carried out separately for anthracene and naphthacene emissions isolated by suitable filters. It has been observed that the decay curves

are practically identical. In the glow curve for anthracene-naphthacene system, a very weak peak is observed.

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Abstract.

The luminescence spectra of Naphthalene, Diphenyl, Phenanthrene, Triphenyl methane, Anthracene, etc., excited by X-rays and cathode rays at room temperature as well as at liquid oxygen temperature are reported in this paper. Most of these phosphors show a long period afterglow. The decay of the long period afterglow of some of these phosphors under cathode rays has been measured at liquid oxygen temperature; the glow curves for some of these samples have also been recorded.

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SOME ASPECTS IN THE EMBRYOLOGY OF ZYGOGYNUM BAILLONI V. TIEGH.

By B. G. L. SWAMY, *Research Fellow, N.I.S.I., Botany Laboratory, Madras University, Madras.*

(Communicated by Prof. P. Maheshwari, F.N.I.)

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The family Winteraceae occupies a rather significant position—especially on account of its vesselless xylem and the remarkably complete series of stages that its members present in the phylogenetic closure of the unsealed conduplicate carpel—in studies concerning the phylogeny of angiosperms. The recent investigations of Prof. I. W. Bailey and his associates (see Bailey and Nast, 1945, for a summary and literature) have greatly enlightened our knowledge in regard to the anatomy and morphology of the vegetative structures of the family. However, very little is known as to the internal development and organisation of the reproductive structures. The casual observations of Willie (1886) on the pollen of *Drimys Winteri*, of Strasburger (1905) on the development of the ovule, and of Bhagavathi Kutti Amma (1938) on the microsporogenesis of the same species are the only contributions towards the embryology of the family.

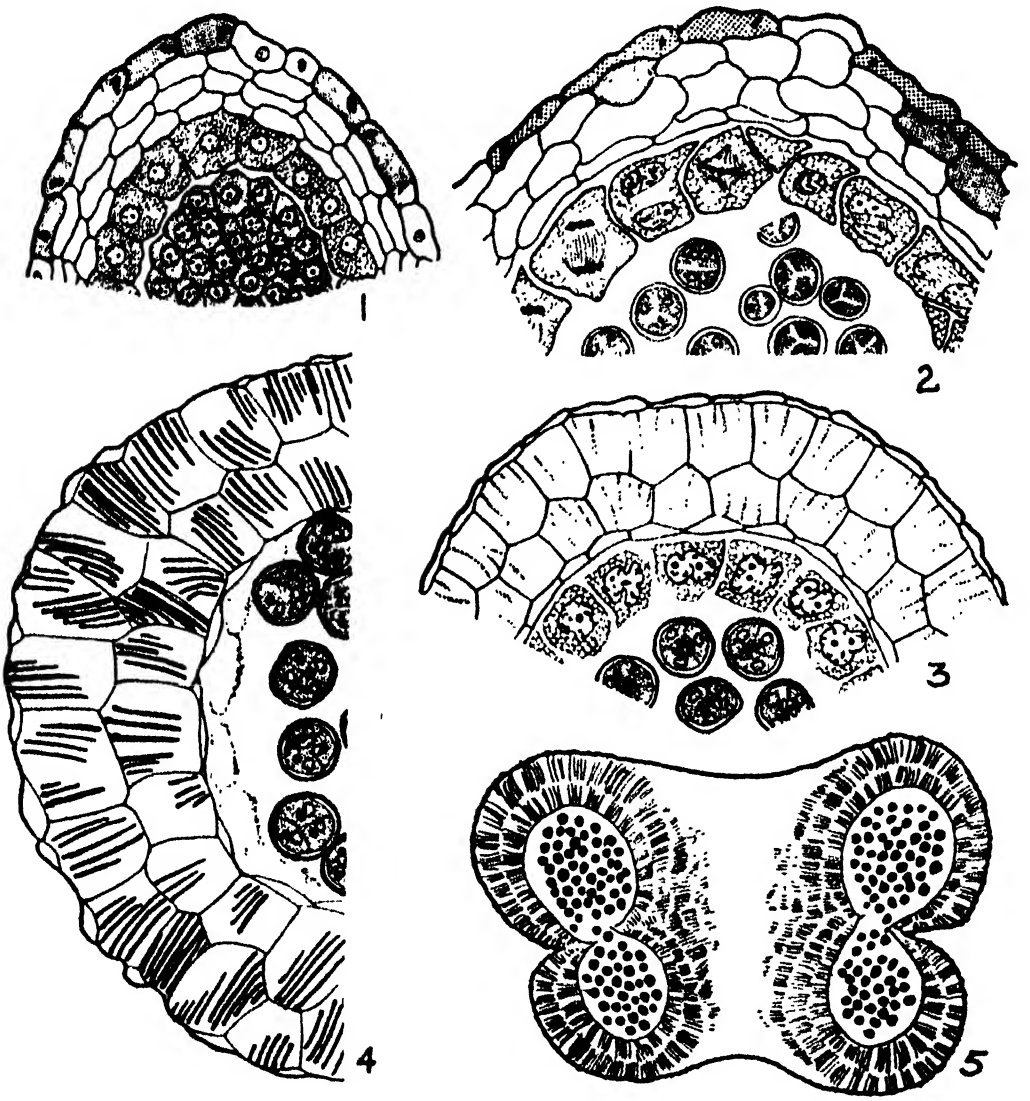
The genus *Zygogynum* with its six recognised species is endemic in New Caledonia. In 1948, the late Prof. J. T. Buchholz visited this island on a plant collection trip and brought back with him a small quantity of flowers and maturing fruits fixed in FAA. This material was forwarded to Prof. I. W. Bailey of Harvard University and has formed the basis for present study.

OBSERVATIONS.

Microsporogenesis.—The wall of the youngest anthers available to me shows an epidermis, several cells of which are filled with brownish phenolic compounds, three subepidermal layers of parenchymatous cells, and an innermost layer of larger tapetal cells containing minutely vacuolate, granular-appearing, dense cytoplasm with a centrally situated nucleus. The interior of the loculus is occupied by a rather massive aggregation of microspore mother cells (Fig. 1). In the course of maturation, the epidermis as well as the wall layer lying immediately outside the tapetum become almost disintegrated, whereas the two layers of cells in between these enlarge, essentially in a radial direction, and develop the characteristically banded thickenings of the endothecium (Figs. 3, 4). In still older stages the wave of differentiation of the endothecial thickenings spreads to two to four more layers of cells towards the interior of the anther (Fig. 5).

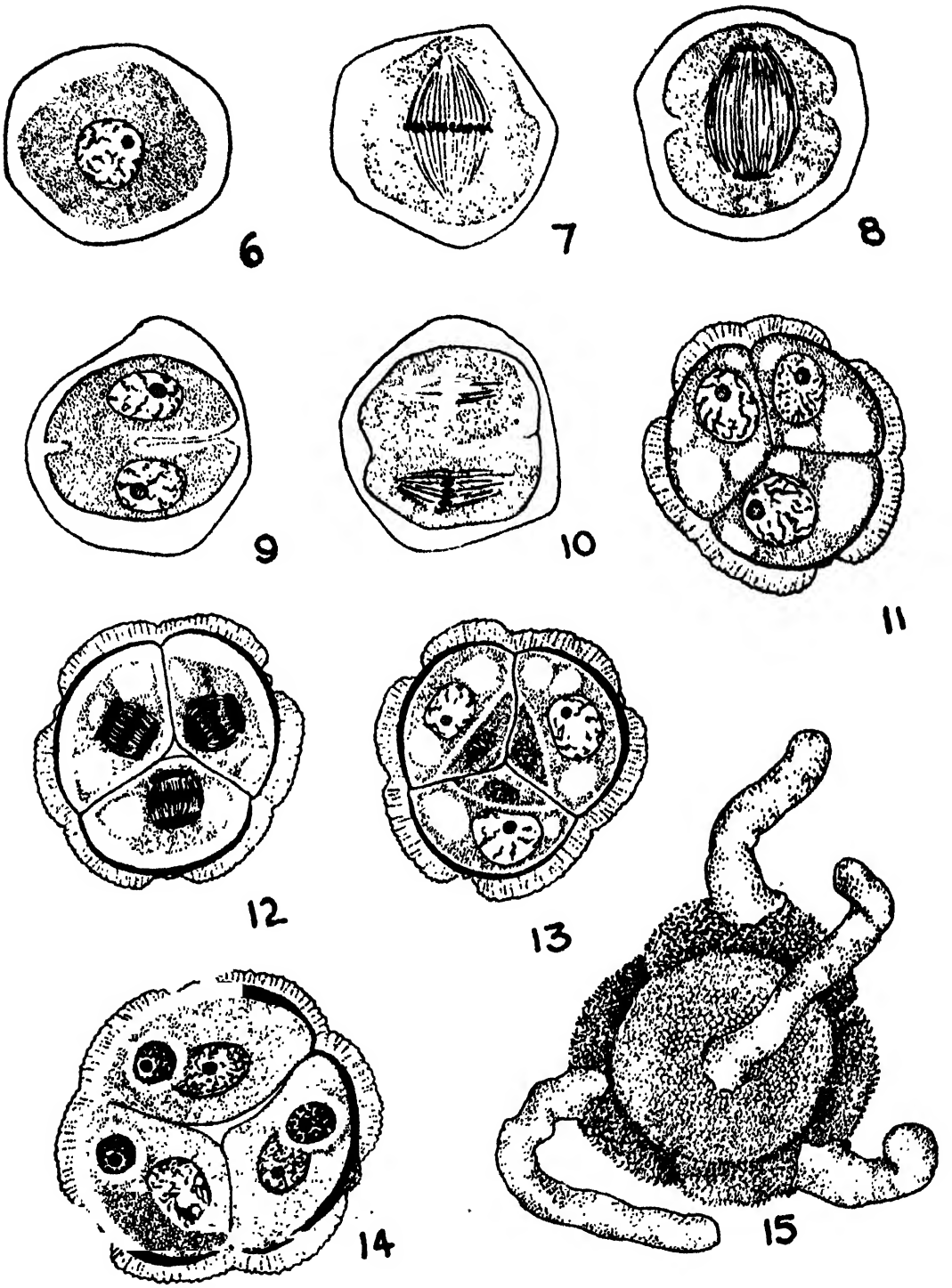
At the time of quadruplication of the microspores, the tapetum embarks on its active phase. The cells distend, the vacuoles become larger, the texture of the cytoplasm coarser, and the nuclei divide into two (Fig. 2). When the microspores complete the cutting off of the generative and vegetative cells, the once divided tapetal nuclei exhibit stages in reunion (Fig. 3). The maximum activity of the nutritive layer appears to diminish gradually after complete fusion of the nuclei; the cell wall together with the cytoplasm becomes very coarsely granular, the nuclei degenerate, and at the time of differentiation of the spore walls, the entire tapetum disintegrates *in situ* (Fig. 4).

The microspore mother cell rounds off by losing its polygonal contour and considerably enlarges before commencing the reduction divisions (Fig. 6). Organisation of a metaphase spindle (Fig. 7) is accomplished with the usual succession of changes accompanying normal meiosis, and while the daughter chromosomal groups



FIGS. 1–5. Fig. 1. Transection of a young anther loculus showing epidermis, three middle layers, tapetum, and microspore mother cells, ×200. Fig. 2. Same, at a later stage, showing nuclear division in the tapetal cells, ×200. Fig. 3. Still older stage, showing the fusion of the nuclei in the tapetal cells, and the beginnings of endothecial thickenings in the two subepidermal layers, ×200 Fig. 4. Same, at maturity, showing the disorganisation of tapetum *in situ*, and a well developed two-layered endothecium, ×200. Fig. 5. Transection of an anther at anthesis, showing the extent of endothecial tissue (semi-diagrammatic), × 60.

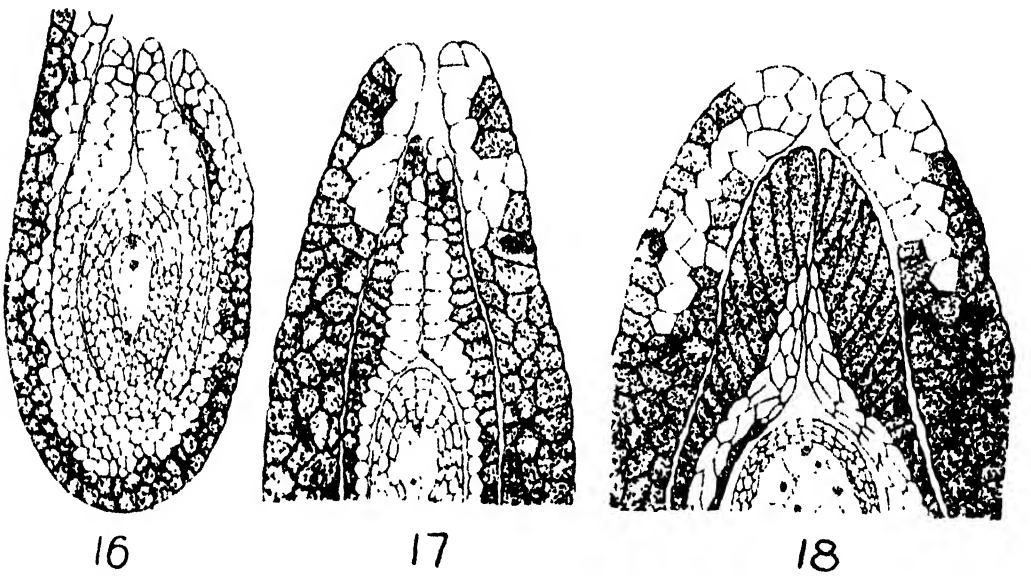
are passing through the later stages of anaphase, the cytoplasm shows the beginnings of an equatorial constriction (Fig. 8). At the time of preparation of the daughter nuclei (Fig. 9) for the ensuing division II (Fig. 10), the constriction advances centripetally in the form of a furrow and at times an incipient cell plate



FIGS. 6–15. Stages in development of pollen grain. Fig. 6. Microspore mother cell. Fig. 7. Metaphase of division I. Fig. 8. Late anaphase of division I. Fig. 9. After telophase I, note commencement of transverse furrow. Fig. 10. Metaphase of division II. Fig. 11. Tetrad of microspores. Fig. 12. Division of microspore. Fig. 13. Formation of generative and vegetative cells. Fig. 14. Tetrad of microspores at the time of shedding. Fig. 15. Germinating tetrad teased out from stigmatic surface. All figures, ×900.

may also be deposited partially (Fig. 10). However, total quadripartitioning is achieved more or less simultaneously only after the completion of division II (Fig. 11). In the greatest majority of cases the microspores are arranged tetrahedrally, a tetragonal configuration being exceptional (Fig. 10).

The uninucleate microspore, soon after its formation, exhibits a few large vacuoles in the cytoplasm (Fig. 11). The nucleus moves towards the proximal pole (in relation to the tetrad) and divides (Fig. 12). The orientation of the spindle is consistently such that the generative cell is always cut off towards the inner, proximal side (Fig. 13). The larger vegetative cell with its nucleus of similar magnitude continues to show the presence of a few large vacuoles, while in contrast the smaller generative cell has a non-vacuolate, dense, deeply staining cytoplasm and a nucleus of similar dimension and staining reactions. At a little later stage the generative cell comes to lie within the cytoplasm of the vegetative cell by which time the cytoplasm of the latter has become non-vacuolate and homogeneous, and that of the generative cell, on the other hand, hyaline (Fig. 14). The position occupied by the generative cell is now variable even among the different pollen

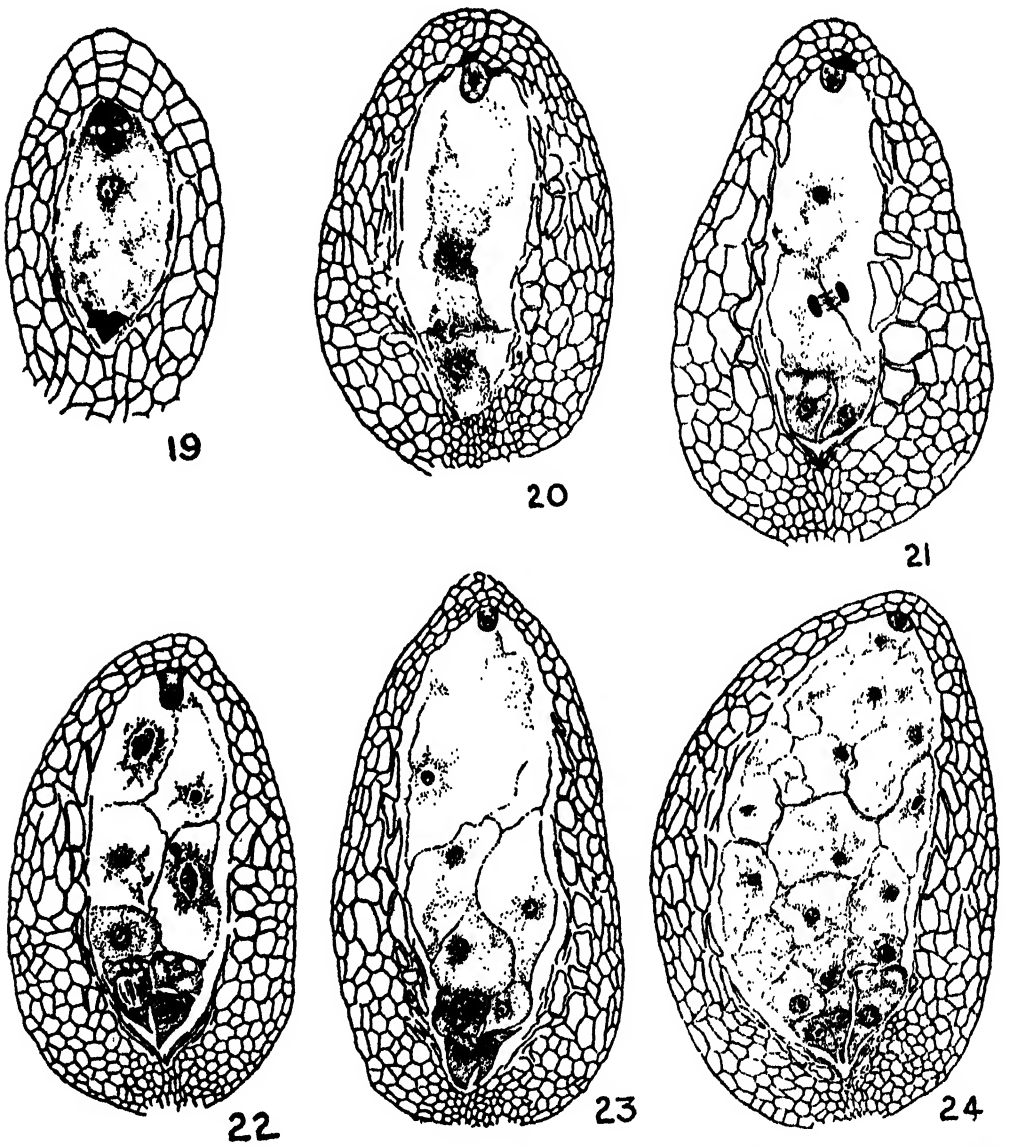


Figs. 16–18. Fig. 16. Longisection of ovule at the time of fertilisation, ×120. Fig. 17. Micropylar part of same, about the 4-celled stage of endosperm, ×80. Fig. 18. Same, at a slightly later stage, ×60.

grains of the same tetrad. The generative nucleus continues to exhibit a greater avidity for stains while the vegetative nucleus behaves in the reverse direction. The microspores of a tetrad do not separate from one another and germinate as such (Fig. 15) on the stigma.

The property of the microspores to adhere in tetrads affords special facility to determine the exact place of origin and differentiation of the germinal area. Soon after the completion of division II, the spore walls begin to organise. Until the stage shown in Fig. 10, the wall of the mother cell appears as a uniformly thick and highly translucent envelope surrounding the protoplast. Simultaneously with quadruplication through furrowing there is a rapid thinning out of the wall at the central region on the distal face of the microspore. This results in the formation of a shallow pit, which, as seen in a section, appears as a discontinuous region of the spore wall (Fig. 11). This break in the wall later functions as the germ pore (Figs. 12–15). Accompanying these modifications of the external surface of the

spore, there is also accomplished a differentiation of the exine and intine. A major bulk of the thick spore wall towards the exterior appears to become traversed by numerous, highly tenuous capillaries so as to present a radially striated pattern as seen in sections. This part of the wall functions as the exine, and due to



FIGS. 19–24. Longisections of ovules (integuments not shown) illustrating the early stages in the development of endosperm. Fig. 19. Embryo sac at the time of fertilisation, ×220. Fig. 20. Same, after first division of the primary endosperm nucleus, ×220. Fig. 21. Same, at about the 5-celled stage of endosperm, ×220. Figs. 22–24. Later stages, ×120.

this structrual detail, presents the characteristic minutely granular-reticulate sculpturing in the mature pollen grain (Fig. 15). In the initial stages the intine becomes discernible as a thin membrane immediately underlying the germ pore, and gradually extends all over the distal sphere of the cell. However, it presents

maximum thickness at the region of the germ pore and steadily thins out towards the sides. A differentiation *pari passu* results in the slight protrusion of the intine through the germ pore (Fig. 14) long before the dehiscence of the anther.

The germination of the pollen grain takes place in nature only after its transference on to stigma. The intine pushes itself out through the germ pore to form the pollen tube. The emergence and early growth of pollen tubes from a tetrad are synchronous (Fig. 15).

Ovule.—At anthesis, the ovule shows a completely organised, fertilisable embryo sac, the micropylar region of which is over-topped with four or five layers of parietal tissue. The outer integument at this stage is made up of three layers of cells towards the micropylar half and irregularly of four layers towards the base. The cells of the outer two layers show conspicuous brownish infiltration indicated by stippling in Fig. 16. The inner integument is two layered towards the micropyle and gradually becomes three layered towards the chalaza. Also, both the cell layers in the micropylar part of this integument are conspicuously distended. After fertilisation, brownish contents rapidly appear not only in almost all cells of the outer integument, but also in the outer cell layer of the inner integument (Fig 17). In still later stages, when the embryo sac cavity becomes obliterated due to the filling in of large endosperm cells, the cells of the outer layer of the inner integument in the micropylar region become excessively elongate in a radial direction, whereas those of the inner layer divide to give rise to two or three more layers (Fig. 18).

Endosperm.—The mature embryo sac is normal both in its contained number of nuclei and in their disposition. The polar nuclei fuse before fertilization. The antipodals organise into cells (Fig. 19). Both the synergids appear to undergo degeneration soon after fertilisation. The primary endosperm nucleus may be assumed to migrate slightly towards the chalazal end as can be judged by the disposition of the wall ensuing the first division (Fig. 20). As a result, the embryo sac cavity becomes halved into a larger micropylar chamber and a smaller chalazal chamber. The latter invariably shows a denser and darkly staining accumulation of cytoplasm and this feature seems to be carried through considerably to its derivatives, perhaps even up to slightly later stages than is represented in Fig. 24, as may be evidenced by a clear gradient in the intensity of staining of the endosperm tissue from the chalazal pole towards the embryo (Figs. 21–24). There is also a graded difference in the nuclear size of the respective cells (Figs. 23, 24), although this feature may not be manifest at the two-celled stage of the endosperm (Fig. 20). Subsequent divisions of both the larger micropylar and the smaller chalazal chambers obviously proceed at the same rate, so that cells of corresponding sizes are derived. However, the sizes soon intergrade in the border zone. The oldest stage of endosperm that was observed is illustrated in Fig. 24, and until this time the zygote has not divided.

Discussion.

Neither detailed comparison nor comprehensive discussion is possible at present with regard to the embryological characters of *Zygogynum*. Of the six known genera,—*Drimys*, *Bubbia*, *Belliolum*, *Exospermum*, *Pseudowintera*, and *Zygogynum* —of the Winteraceae,[1] only *Drimys* has been studied from the point of view of embryology; the information available is, however, too meagre to allow dependable conclusions.

The casual remarks of Willie (1886) on the properties of the spore walls of *Drimys* pollen grain, taken by itself, are of very little significance for the present

[1] See Smith, A. C., in Jour. Arnold Arb. 24: 1–33, 119–164. 1943.

purpose. The observations of Bhagavathi Kutti Amma (1938), although accompanied by a series of illustrations, fail to provide an accurate picture of the sequence of events, and several points therein are badly in need of critical reinvestigation. It is not clear from her account whether it is the tapetal *cells* or *nuclei* that undergo division; nor has it been ascertained whether the once divided nuclei reunite. Furthermore, she writes that, 'In the metaphase stage of the pollen mother cell, the tapetal cells lose their walls completely and persist as a mass of cytoplasm with one or two nuclei in each. They encroach in between the pollen mother cells.... When tetrads are formed, the tapetal cytoplasts completely fuse together and become the periplasm. The nuclei become amoeboid and lie free in the periplasm'. The sequence of events obviously is indicative of the organisation of tapetal periplasmodium. If this observation is correct, *Zygogynum* deviates from *Drimys* in exhibiting a typically secretory type of tapetum.

Although Bhagavathi Kutti Amma does not describe the details involved during the first division of the microspore in the text, she has provided illustrations (see her figure 19, Pl. III, figures 10, 11, Pl. IV) which clearly demonstrate that the generative cell is cut off towards the proximal pole of the pollen grain and that the germ pore is organised on the distal face. Both these features are also shared by *Zygogynum*. The constancy in the locus of the generative cell (towards the proximal pole) in the Winteraceae provides a good point of contrast with that (towards the distal pole) in the Magnoliaceae *sensu stricto*[1] (unpublished observations of the author on species of *Michelia*, of *Magnolia*, of *Tauluma*, and *Liriodendron*) and its close relative, the Degeneriaceae (Swamy, 1949).

Strasburger (1905) reports a nuclear type of endosperm development in *Drimys Winteri*. If this is correct, both nuclear and cellular (*Zygogynum*) types occur within the family.

The conspicuous radial elongation of the outer layer of cells of the inner integument in the region of the micropyle during post-fertilisation development of *Zygogynum* appears to be a constant feature also in *Drimys* and *Bubbia* (unpublished observations of the author). Such a differentiation is absent in the corresponding tissue of the Magnoliaceae. A much more significant point of difference lies in the structure of the seed coat. As could be ascertained from herbarium specimens of *Zygogynum* and *Bubbia*, and also from the generality of observations of Miers (1858) on *Drimys*, the seed structure of the winteraceous genera appears to be rather uniform. The cells of the outermost layer of the outer integument develop dark sclerotic walls and alone persist in the mature seed as a black, shiny crest; all other cell layers of the outer and inner integuments become crushed. In marked contrast, in the seeds of the Magnoliaceae and Degeneriaceae, the outer integument becomes characteristically differentiated into outer fleshy and inner stony regions, the former becoming pulpy and juicy at maturity.

In the prevailing well-known systems of angiosperm classification it has been the custom to assign *Drimys* and its presumed allies to the Magnoliaceae either as members of a special tribe or a subfamily, implying a rather close natural relationship. The recent investigations of Prof. I. W. Bailey and his collaborators have clearly demonstrated—at least as far as the vegetative characters are concerned—that the trends of phylogenetic specialisation have progressed along divergent lines among the different units of the Magnoliaceae, and that 'to include such morphologically dissimilar elements as the Winteraceae, *Illicium*, the Schisandraceæ, and *Tetracentron* in the Magnoliaceae broadens the concept of this family even beyond the limits of a natural suborder'. With particular reference to the Winteraceae, Bailey and Nast (1945) conclude that although the genera of the family are of general ranalian affinities, 'they do not appear to be closely related to any specific surviving family of the ranalian complex' (see also Bailey and Smith, 1942). The

[1] See Dandy, J. E., in Kew Bull. 1927, pp. 257–264.

few salient points of contrast in the embryological characters of the Winteraceae on the one hand and those of the Magnoliaceae and Degeneriaceae on the other, as presented above, appear to indicate two very remotely related trends of evolutionary modifications, thereby justifying the dissociation of the Winteraceae from the magnoliaceous alliance.

Summary.

The precocious appearance of cytoplasmic cleavage towards the end of the first reduction division in the microspore mother cell, and the differentiation of endodermal thickenings in more than one layer of cells of the anther wall are points of interest in *Zygogynum Baillonii*.

The tapetum is of the secretory type, the cells becoming binucleate and finally again uninucleate due to fusion.

The generative cell is cut off towards the proximal pole and the germ pore differentiates on the distal face of the grain.

The ovule is bitegumentary and crassinucellate. The mature embryo sac is eight nucleate with typical organisation. The endosperm is *ab initio* cellular. The seed coat consists of the modified outermost cell layer of the outer integument. The outermost cell layer of the inner integument in the neighbourhood of the micropyle undergoes pronounced radial elongation during early post-fertilisation development.

The embryological characters of the Winteraceae, on the one hand, and of the Magnoliaceae and Degeneriaceae, on the other, appear to indicate two very remotely related trends of evolutionary modifications, thereby justifying the dissociation of the Winteraceae from the magnoliaceous alliance.

Acknowledgments.

I thank Prof. I. W. Bailey of Harvard University for placing the preserved material at my disposal for study. I am grateful to the National Institute of Sciences of India for the award of a Fellowship, which has made this investigation possible, and to Prof. T. S. Sadasivan and the Madras University for extending me the privilege of working in the University Botany Laboratory, Madras.

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PARALLEL EVOLUTION OF THE GASTROMYZONID FISHES ON THE MAINLAND OF ASIA AND IN THE ISLAND OF BORNEO.

By SUNDER LAL HORA, *D.Sc., F.R.S.E., C.M.Z.S., M.I.Biol., F.A.S., F.Z.S.I., F.N.I., Director, Zoological Survey of India, Indian Museum, Calcutta.*

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INTRODUCTION.

In his 'Zoogeography of the land and inland waters', de Beaufort (1951, p. 88) makes the following statement about the interrelationships and geographical affinities of the Gastromyzoninae of Borneo:

> 'In mountain torrents of northern Borneo certain curious fishes are found belonging to the Homalopteridae. Among fishes in this group they have gone farthest in the way of adaptation to life in fast-running water, as the whole flat underside, surrounded by the much expanded pectoral and pelvic fins, forms a large sucker by which the fish can adhere to stones or rocks. Two genera, *Gastromyzon* and *Neogastromyzon*, are known from Borneo, but closely allied forms are found in the mountain streams of southern China. They are unknown from Java, Sumatra, Malaya, or Siam; and the most probable explanation of their occurrence in Borneo is that they came by a direct route from China. This involves a connection between Borneo and China of some altitude, for it is not probable that these fishes could disperse through lowland rivers. Nor is it probable that they used the Pleistocene land bridge through the Philippines and Formosa, for in that case we should expect to find Gastromyzoninae in the mountains of these islands. As the two Bornean genera are endemic, it is also improbable that they reached Borneo so late. They seem to belong to an older invasion, and their occurrence in the upper course of the Mahakam is in favour of this view'.

In 1932, I proposed a classification of the Homalopteridae and suggested their polyphyletic origin. The two subfamilies into which they were grouped were divided into genera and it was shown that the union of pelvic fins to form a sucker had occurred independently in the two subfamilies, *Sinogastromyzon* of the Homalopterinae and *Gastromyzon*, *Neogastromyzon* and *Beaufortia* of the Gastromyzoninae. Since then, *Metahomaloptera* among the Homalopterinae has also been described with the same character. Though the adaptive nature of this character cannot be denied, no genetic significance can be attached to it, similarly as reduction of gill-openings has taken place in several diverse groups of fishes in which the ventral surface is closely applied to a hard substratum. In this paper, it will be shown that the Gastromyzonid fishes of Borneo had an independent, though parallel,

evolution from a generalized Cobitid stock and are in no way genetically related to the similar forms found in China. From a considerably wider distribution of the Homalopteridae and a somewhat restricted distribution of the Gastromyzonidae, it is abundantly clear that the former is much older than the latter, so the Gastromyzonidae could not be older than the late Pliocene when no direct connection existed between China and Borneo (*vide* de Beaufort, 1950, fig. 7, p. 86). We shall now examine the question in greater detail.

In a recent paper, I (1950), p. 46) referred to the polyphyletic origin of the family Homalopteridae and suggested its division into two families, Homalopteridae derived from the Cyprinidae and Gastromyzonidae derived from the Cobitidae. Fang (1935, p. 44) had already recognised two distinct groups of fishes among the Gastromyzonidae which he distinguished by the following characters:

> 'Crossostomoid fishes are small forms inhabiting the mountain torrents. They are well separated from the gastromyzonian fishes in having the gill openings extending to the ventral side of body and the pectoral fins set immediately behind them.'

Fang published a review of the Crossostomoid fishes of China which he derived from a 'Nemachiloid ancestral stocks'. Further, he regarded them as having been evolved independently along three lines, namely, (i) *Annamia* Hora; (ii) *Liniparhomaloptera* Fang and *Parhomaloptera* Vaillant, and (iii) *Vanmanenia* Hora, *Praeformosania* Fang, *Formosania* Oshima and *Crossostoma* Sauvage. Though one may not agree with Fang's views of the inter-relationships of the various Crossostomoid genera, it is certainly true that they form a heterogenous assemblage of independently evolved forms under the stress and strain of the very exacting environmental factors so characteristic of the torrential streams of south-east Asia.

Further support is lent to this view by the fact that the typical Gastromyzonid fishes, characterized by small gill-openings restricted to the dorsal and lateral sides and not extending to the ventral surface, also show several independent lines of evolution. The most striking fact is perhaps a uniformity of structure among the genera known from the mainland of Asia and their divergence collectively from the genera known from Borneo. In this article an attempt is made to define these two divergent groups of Gastromyzonid fishes and to indicate their independent evolution.

Distribution and Characterization of the Gastromyzonid Genera.

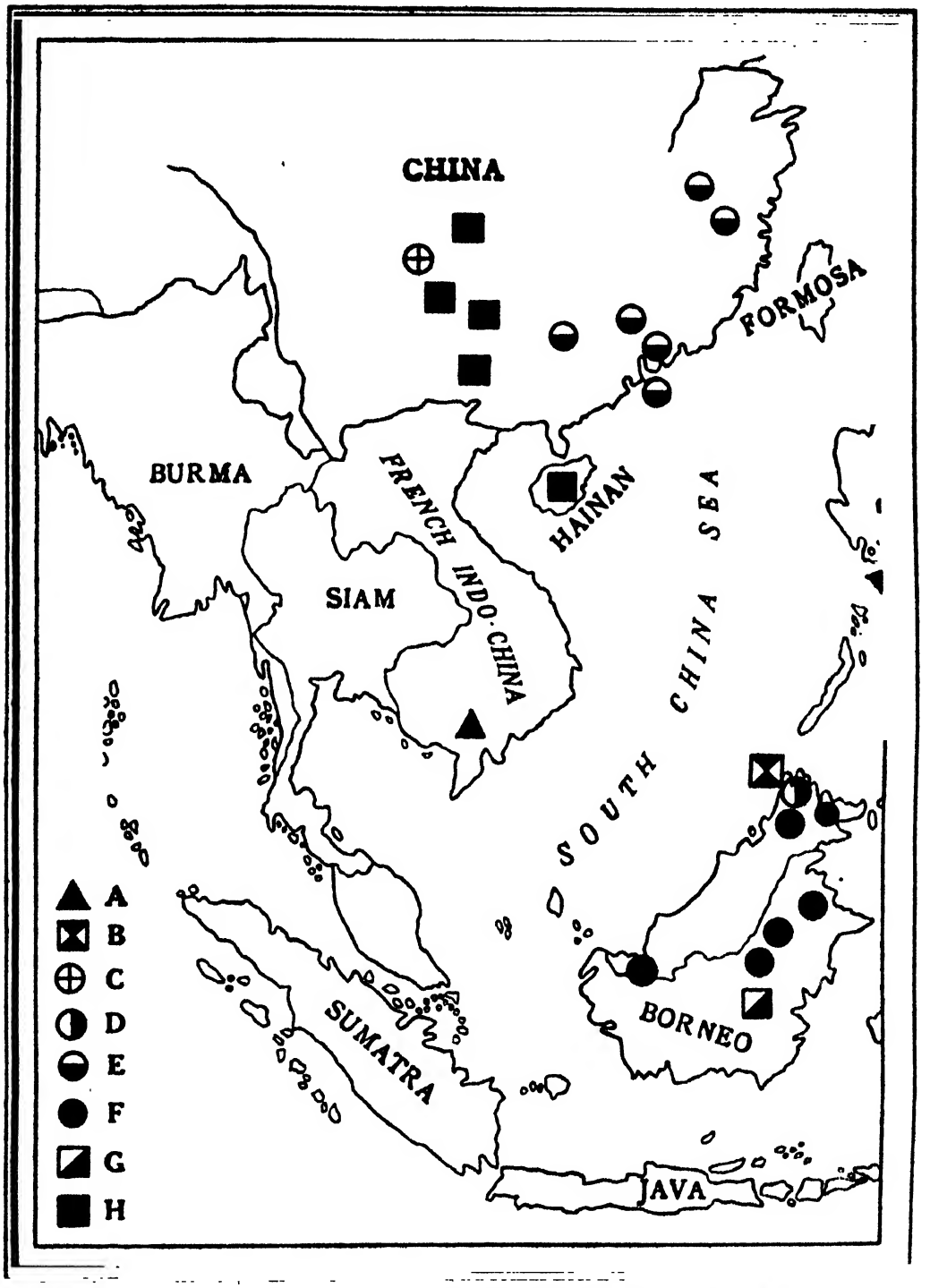
According to their distribution, the eight Gastromyzonid genera known so far can be arranged into two geographical units as given below:

Mainland of Asia.

(1) *Paraprotomyzon* Pell. & Fang	.. Szechuan, China.
(2) *Pseudogastromyzon* Nichols	.. Fukien, China.
(3) *Beaufortia* Hora	.. Hainan, Kwangsi & Szechuan, China.
(4) *Sewellia* Hora	.. Cochin-China.

Island of Borneo.

(1) *Protomyzon* Hora ..	.. Mt. Kina Balu, Borneo.
(2) *Neogastromyzon* Popta ..	.. Howong, Borneo.
(3) *Progastromyzon* Hora & Jayaram	.. Mt. Kina Balu, Borneo.
(4) *Gastromyzon* Günther ..	.. Torrential streams, Borneo.



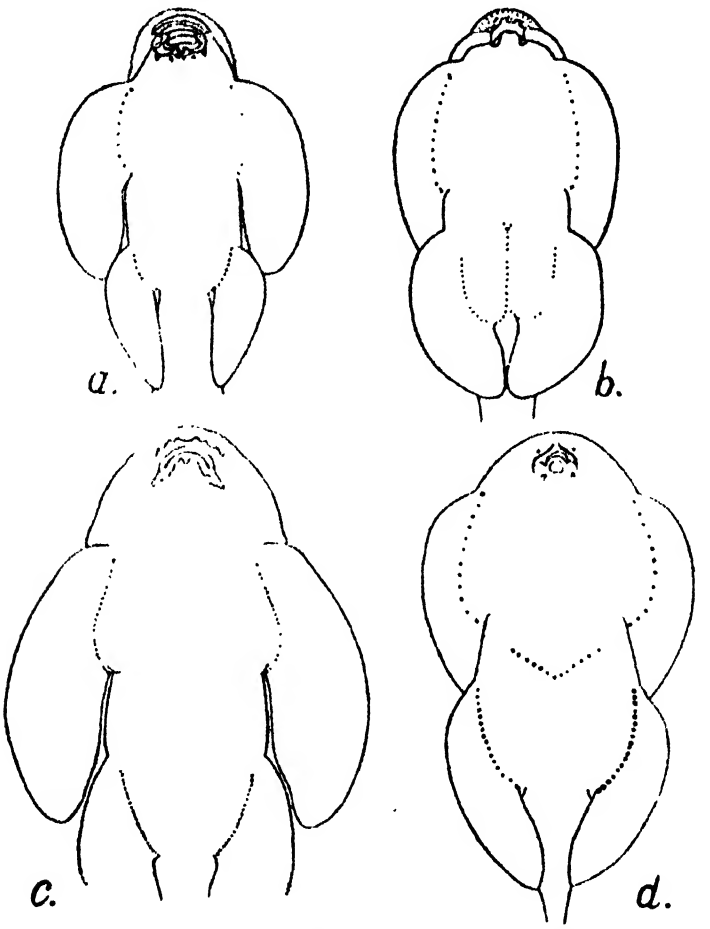
TEXT-FIG. 1. Map showing the distribution of the Gastromyzonid fishes.

A. *Sewellia* Hora; B. *Progastromyzon* Hora and Jayaram; C. *Paraprotomyzon* Pell. and Fang; D. *Protomyzon* Hora; E. *Pseudogastromyzon* Nichols; F. *Gastromyzon* Günther; G. *Neogastromyzon* Popta; H. *Beaufortia* Hora.

It may be noted that no genus of the mainland is found in Borneo and *vice versa*. It may also be noted that no Gastromyzonid fish has yet been recorded from Java, Sumatra, Malay Peninsula, Siam, Burma and further west. Thus the Gastromyzonid fishes are restricted to comparatively narrow geographical zones within the two regions.

Common and Contrasting Features of the Gastromyzonid Genera.

Common feature.—It has been pointed out above that all the Gastromyzonid fishes, as distinguished from the Crossostomoid fishes, are characterized by the

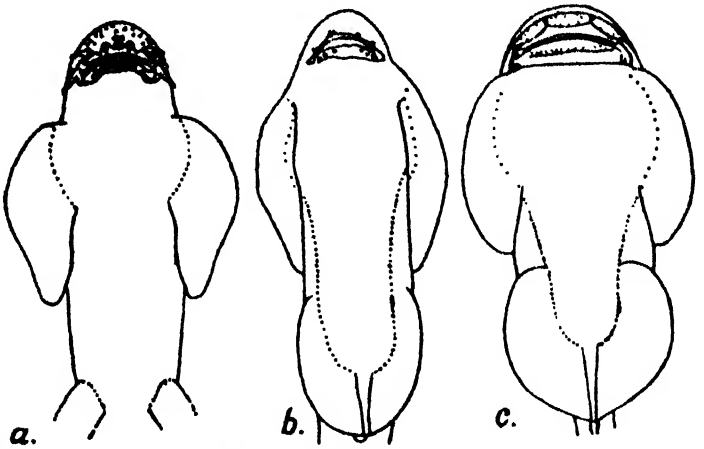


Text-fig. 2. Sketches of the ventral surfaces of the head and body of the Gastromyzonid genera of the Mainland of Asia.

(*a*) *Pseudogastromyzon* Nichols; (*b*) *Beaufortia* Hora; (*c*) *Paraprotomyzon* Pell. and Fang; (*d*) *Sewellia* Hora.

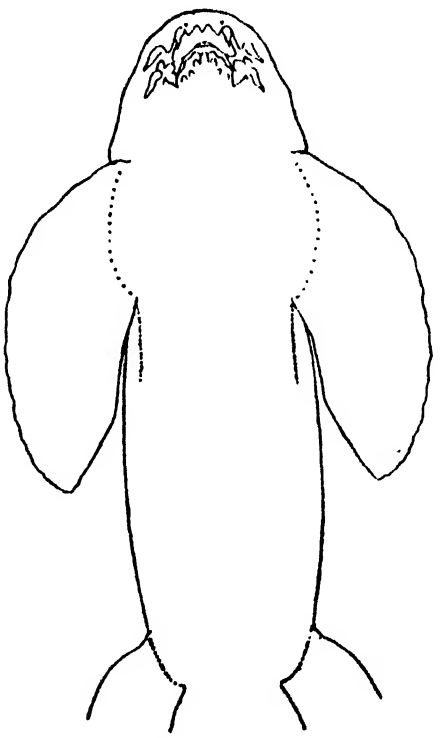
presence of restricted gill-openings. This character is shared by a number of diverse fishes that closely apply their ventral surface to rocks for adhesion. In the hill-streams of South-east Asia, I have found similar modifications among the Glyptosternoid group of Sisorid fishes (Hora & Silas, 1951) and in *Bhavania* Hora (1941) and *Metahomaloptera* Chang (1944) among the Homalopteridae. Though it is a useful taxonomic character, as explained already, it is a purely adaptive feature and, therefore, no phylogenetic significance can be attached to it.

Contrasting features.—In all the mainland genera, the pectoral fins extend beyond the bases of the pelvic fins so that the ventral surface enclosed between them can act as a sucker for adhering to rocks in swift currents. Another



EXT-FIG. 3. Sketches of the ventral surfaces of the head and body of three Gastromyzonid genera of Borneo.

(*a*) *Progastromyzon* Hora and Jayaram; (*b*) *Neogastromyzon* Popta; (*c*) *Gastromyzon* Günther.



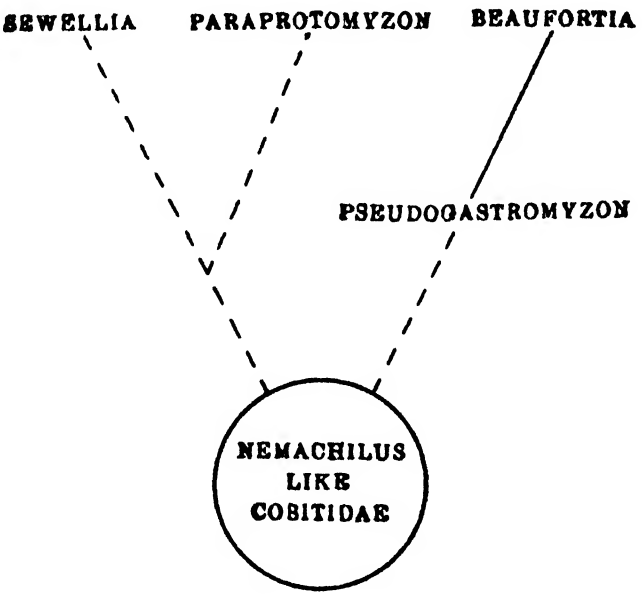
TEXT-FIG. 4. Sketch of the ventral surface of the head and body of the Bornean Gastromyzonid fish *Protomyzon* Hora.

characteristic feature of these genera is the small size of the mouth, which is less than one-third of the width of the head.

In the Bornean genera, on the other hand, the pectorals are separated from the pelvics by a considerable distance, but in highly specialized forms, such as *Gastromyzon* and *Neogastromyzon*, lateral flaps of skin are developed to bridge over the space between the paired fins so as to convert the ventral surface into a suctorial disc. Thus we have a functional convergence achieved through divergent modifications of structures. As regards the extent of the mouth, the four Bornean genera are divisible into two groups. In *Progastromyzon*, *Gastromyzon* and *Neogastromyzon*, the mouth is very extensive and is more than half of the width of the head, while in *Protomyzon* the mouth is about one-third of the width of the head. In any case, it is still of a different type than that characteristic of the mainland forms.

Relationships of the Gastromyzonid Genera.

In dealing with the common and contrasting features of the mainland and Bornean genera, it has been shown that whatever may have been their ancestral stocks, they have collectively shown independent lines of evolution in regard to

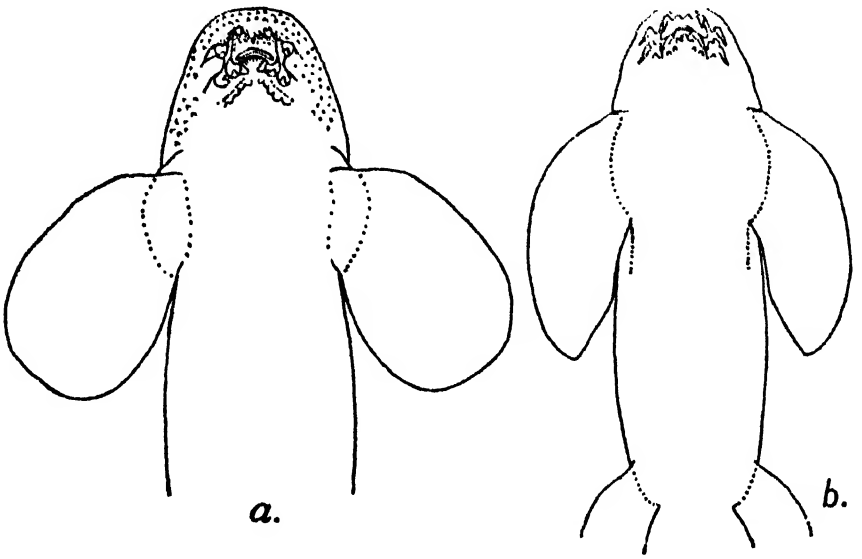


Text-fig. 5. Diagrammatic representation of the probable relationships of the mainland Gastromyzonid genera.

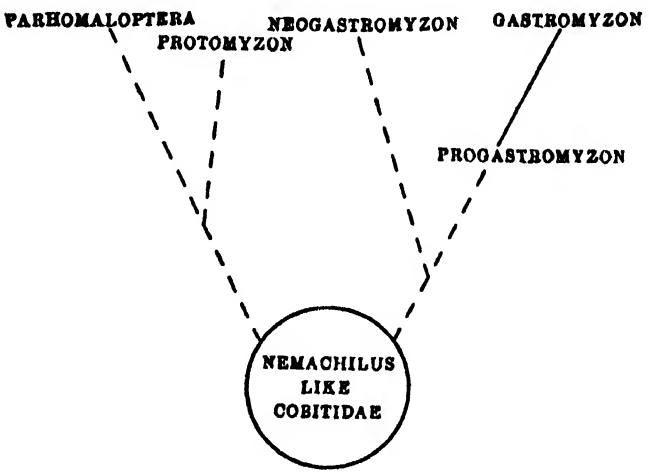
the characters of the paired fins, skin flaps and form of mouth. It is interesting to recall here that from the study of scales, Law (1950, p. 82) found a closer affinity between *Protomyzon* and *Gastromyzon* on the one hand and between *Paraprotomyzon* and *Pseudogastromyzon* on the other. The scales of *Beaufortia* were found to be quite different from either. We may now examine the inter-relationships of the genera in each geographical group.

The four genera of the mainland do not show any direct linear relationships and perhaps many forms yet remain to be discovered before we can tell the complete story of their evolution. *Sewellia* Hora (1932, p. 315), both on account of its geographical isolation in Cochin-China, as well as its peculiar respiratory mechanism and plate-like rostral barbels, seems to be quite distinct from the other three genera. Of the remaining three genera, *Paraprotomyzon* Pell. & Fang (1935) may possibly have separated off from the *Sewellia* stock at an early stage. *Pseudogastromyzon*

Nichols (Hora, 1932) seems to be somewhat more generalized and may have given rise to *Beaufortia* Hora (1932, p. 318). In the union of the pelvic fins to form a sucker, *Beaufortia* is more specialized than all the other genera of the mainland group. With our present imperfect knowledge, we may represent the evolution of these genera as shown in text-fig. 5.



TEXT-FIG. 6. Ventral surface of head and anterior part of body of *Parhomaloptera* Vaillant and *Protomyzon* Hora.
(*a*) *Parhomaloptera* Vaill.; (*b*) *Protomyzon* Hora.



TEXT-FIG. 7. Diagrammatic representation of the probable relationships of the Bornean Gastromyzonid genera.

The four Bornean genera do not show any direct linear relationships either. *Progastromyzon* and *Gastromyzon* suggest the evolution of the latter from the former, while *Neogastromyzon* may have either evolved independently or from the *Progastromyzon-Gastromyzon* stock at a very early stage. The narrow-mouthed *Protomyzon* is certainly quite different from the other three genera. From the structure of its mouth parts, it seems to have been evolved from the Crossostomoid

genus *Parhomaloptera* Vaillant. In fact, *Protomyzon* can be regarded as a *Parhomaloptera* with the gill-openings restricted to the sides and not extending to the ventral surface. We have an exact parallel to this in the two Homalopterid genera, *Bhavania* Hora and *Homaloptera* van Hass. The former is a *Homaloptera* with the gill-openings restricted to the dorso-lateral surfaces. The evolution of the Bornean Gastromyzonid fishes can be represented as shown in text-fig. 7.

It will be presumed from what is stated above that the Gastromyzonid fishes have not only evolved independently from the Cobitid stocks on the mainland of Asia and the island of Borneo, but in each geographical region they show polyphyletism in their mode of evolution. Similar adaptive modifications have occurred again and again among the fishes of the torrential streams of south-east Asia with the result that we have at present very complicated adjustments through convergences and divergences of characters. Only a careful taxonomic assessment of various characters could reveal the true systematic position of the various genera. From the remarkable anticipated discoveries made since the publication of my monograph of the 'Homalopteridae' in 1932, it seems probable that several new forms still remain to be discovered and, when this is done, they will help us to bridge the present-day gulfs in our knowledge and to elucidate correctly the evolutionary trends of these remarkable fishes.

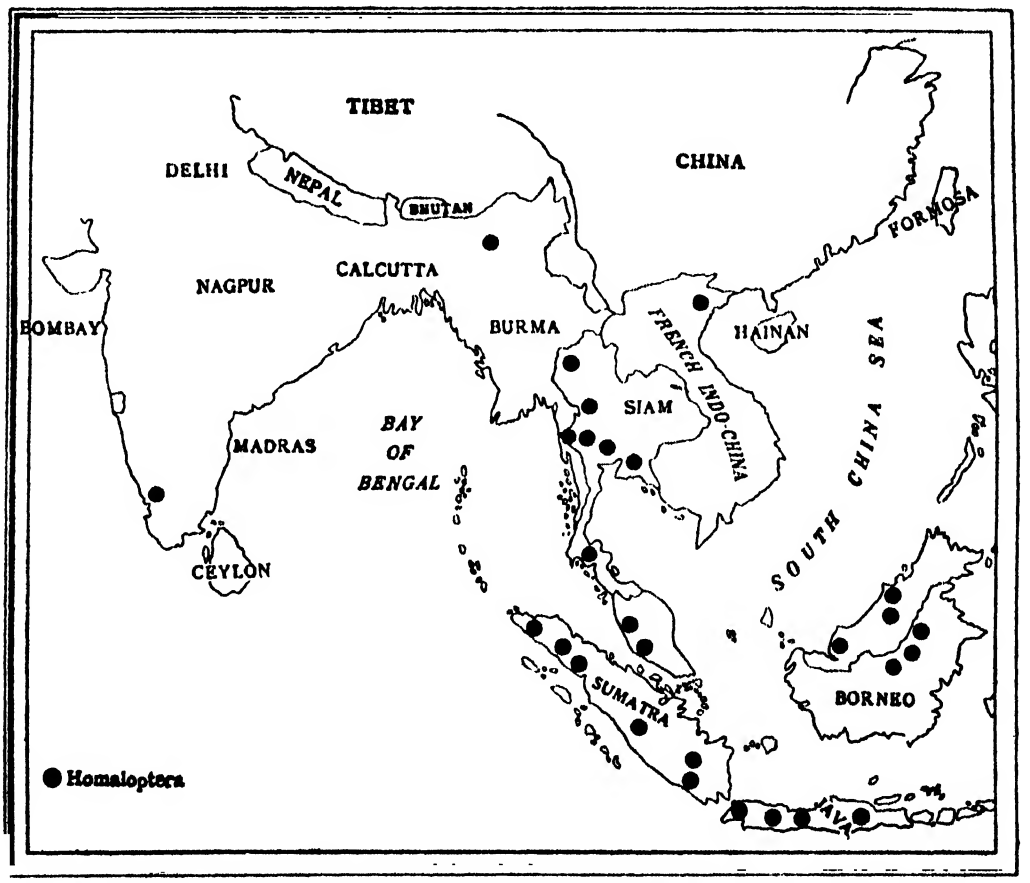
Space and Time in the Evolution of the Gastromyzonid Fishes.

Students of distribution of freshwater fishes of south-east Asia are no doubt aware that the route of dispersal of the specialized hill-stream forms from the mainland of Asia to the islands of the Indo-Australian Archipelago lay along the Malayan Arc of mountains. This is beautifully illustrated by the distribution of the fishes of the genus *Homaloptera* (*sensu lato*). To Borneo, the path from the mainland lay across the Malay Peninsula, Sumatra and Java. Borneo, with the Malay Peninsula, eastern Sumatra, part of the north coast of Java and the sea basin between them constituted the stable block known as Sundaland. Lowlands, however, presented a barrier to the dispersal of mountain species, so mere land connections could be of little use in their distribution. Text-figure 1 will show that the mainland Gastromyzonid fishes are found to the east of the Malayan Arc movements and were, therefore, not affected by this route of migration in their dispersal. This geographical fact supports the view, advanced above on morphological grounds, that the Gastromyzonid fishes evolved independently on the mainland of Asia and in Borneo, and have had no geographical continuity with each other during their evolutionary history. It has to be borne in mind that the Cobitidae, which formed the ancestral stock for the evolution of the Gastromyzonid fishes of Borneo, must have migrated along the Malayan Arc to Borneo much earlier than the period of evolution of the Gastromyzonid fishes.

As to the period taken for the evolution of the *Gastromyzonid* fishes, we have a yardstick in the evolution of the Homalopteridae in Peninsular India. The dispersal of the Cobitidae took place when India and Ceylon, and India and north-east Africa had more or less continuous hilly connections. Between Ceylon and India such a connection existed during the Pliocene (Jacob, 1949) and probably between India and Africa up to the Pleistocene (Menon, 1951). It can reasonably be presumed that Borneo also received its Cobitid fauna in the Pliocene or early Pleistocene. The genus *Homaloptera* is found in the Western Ghats just below the Palghat Gap and two other genera evolved from it, *Bhavania* and *Travancoria*, are found further south, but no Homalopterid fish has yet been recorded from Ceylon. It is presumed that the Homalopterid genera characteristic of Southern India probably came into existence when tilting of the Peninsula elevated the zone of the Western Ghats during the Pleistocene. This tilting of the Peninsular block

rejuvenated the streams in the Western Ghats and produced torrential streams characteristic of the younger mountains, like the Himalayas.

As in the case of the Homalopteridae, in the Gastromyzonidae also the taxonomic differences involved are of generic value, but this must be considered against the factors which might have influenced the evolution of the Gastromyzonidae in two distinct regions. In the author's opinion, the tempestuous environment of torrential streams having been repeatedly disturbed and intestified by the Pleistocene orogenic movements in South-east Asia provided factors of sufficient importance for inducing rapid evolutionary divergences among hill-stream fishes. I am, therefore, led to conclude that the great majority of forms dealt with in this paper are most probably not older than the early Pleistocene.



TEXT-FIG. 8. Map showing the distribution of the genus *Homaloptera* (*sensu lato*).

SUMMARY.

Morphological, palaeogeographical and geological evidences all point to the conclusion that the Gastromyzonid fishes of Borneo evolved independently of those now found on the mainland of Asia. Whereas there is a general plan of similarity of structures in the four genera of mainland, the four genera of Borneo show two independent lines of evolution even with regard to the main characters. There is sufficient evidence to indicate that even the four genera of the mainland had diverged from one another at a very early stage of their evolutionary history. In studying the characters of these genera in relation to the needs of the environment, the conclusion cannot be resisted that the Gastromyzonidae form a convergent group of forms derived from divergent Cobitid species. Though the convergent characters are no doubt due to the similarity in environment, the generic and specific differences are the results of the initial structures possessed by each evolving species.

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PARALLEL EVOLUTION IN THE CROSSOSTOMID FISHES ON THE MAINLAND OF ASIA AND IN BORNEO.

By SUNDER LAL HORA, *D.Sc., F.R.S.E., C.M.Z.S., M.I.Biol., F.A.S., F.Z.S.I., F.N.I., Director, Zoological Survey of India, Indian Museum, Calcutta.*

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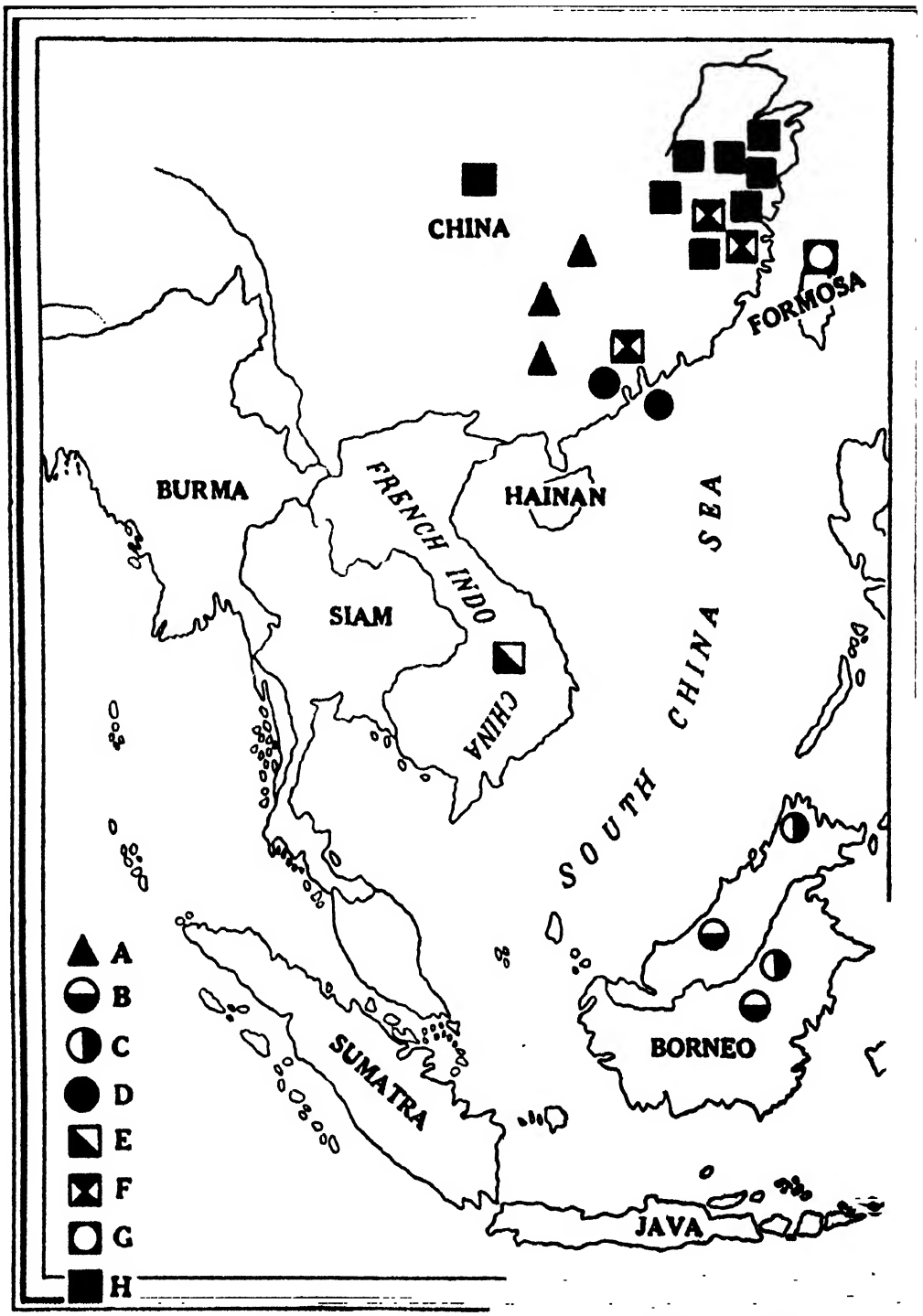
In dealing with the parallel evolution among the Gastromyzonid fishes on the mainland of Asia and in Borneo (Hora, 1952), reference was made to Fang's (1935) paper on the study of Crossostomid fishes of China. Both the Gastromyzonid and Crossostomid fishes pertain to the subfamily Gastromyzoninae (Hora, 1932) which has now been raised to the rank of a distinct family (Hora, 1950). It has also been shown (Hora and Jayaram, 1951, p. 62) that by a simple reduction in the size of the gill-openings and their restriction to the dorsal and lateral surfaces, *Parhomaloptera* Vaillant, a Crossostomid fish, may have given rise to *Protomyzon* Hora, a Gastromyzonid fish. Recently, in a communication, Dr. L. S. Ramaswami has informed that, on the basis of skull structure, *Glaniopsis* Boulenger (see Hora and Jayaram, 1951), and *Protomyzon* Hora are closely related. *Glaniopsis*, according to Dr. Ramaswami, has many characters of *Nemachilus* (Cobitidae) but has also developed some special features of the Gastromyzonidae. Thus in Borneo, we have a group of three genera, perhaps not genetically related, in which we can trace the origin of the Gastromyzonidae from the Nemachilinae of the Cobitidae through Crossostominae to the Gastromyzoninae. Though we have similar groups of genera on the mainland of Asia, it is remarkable that no Crossostomid genus of Borneo is found on the mainland of Asia and, as in the Gastromyzoninae, it seems probable that the Crossostominae of Borneo may have evolved independently from the generalised Cobitid stock.

No new genera pertaining to the Crossostominae have been described since their revision by Fang in 1935. There are six genera from the mainland of Asia, namely *Annamia* Hora, *Liniparhomaloptera* Fang, *Vanmanenia* Hora, *Praeformosania* Fang, *Formosania* Oshima and *Crossostoma* Sauvage. According to Fang (p. 55), *Annamia* and *Liniparhomaloptera* are independently evolved from 'Primitive crossostomoid Fishes (Nemachiloid ancestral stocks)', while the remaining four genera, though evolved from the same stock, form a progressive series of evolutionary changes. There can be no doubt about the unique features of *Annamia*, they are on par with those of *Sewellia* Hora, a Gastromyzonid fish of Indo-China. The relationships of the other genera, however, need further comments.

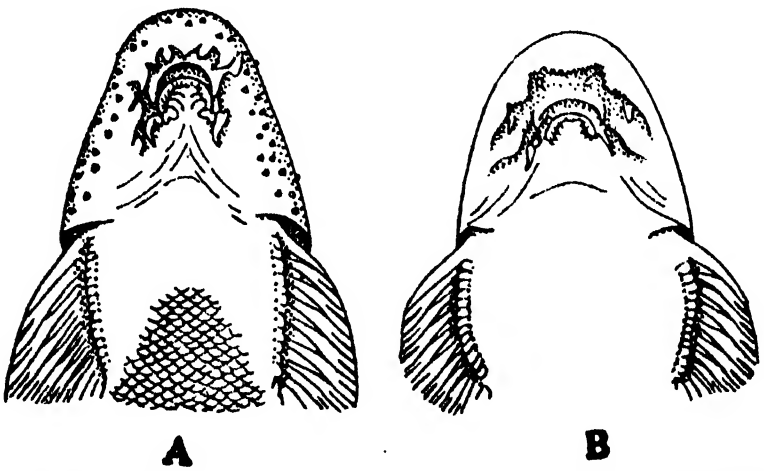
According to Fang, *Liniparhomaloptera* of China directly gave rise to *Parhomaloptera* of Borneo. Unfortunately, sufficient material of these genera is not available to discuss this point from a detailed morphological study of their internal structure. In *Liniparhomaloptera*, the rostral groove is absent (*versus* present in *Parhomaloptera*), the rostral barbels do not arise from the groove but are associated with the rostral fold, the number of rays in the paired fins is P.1/16; V.1/8 (*versus* P.1/16–18, V.1/10 in *Parhomaloptera*) and scales cover a part of the ventral surface between the bases of the pectoral fins. The absence of the rostral groove and disposition of the barbels differentiate *Liniparhomaloptera* from *Parhomaloptera* and show its affinity to a form like *Crossostoma*. I am inclined to regard *Liniparhomaloptera* and *Crossostoma* as having been derived from a common



TEXT-FIG. 1. Map showing the distribution of the Crossostomid genera.

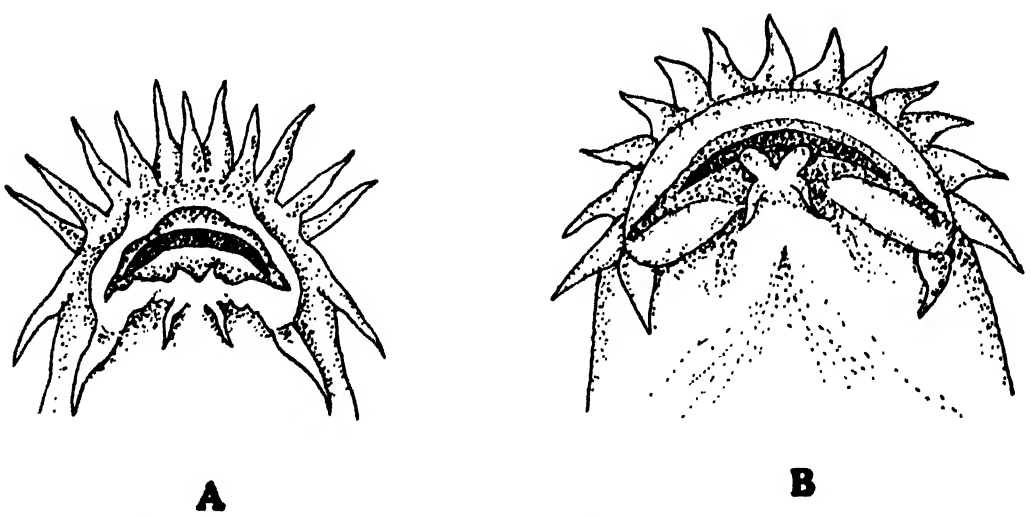
A. Praeformosania Fang; *B. Parhomaloptera* Vaillant; *C. Glaniopsis* Boulenger; *D. Liniparhomaloptera* Fang; *E. Annamia* Hora; *F. Vanmanenia* Hora; *G. Formosania* Oshima; *H. Crossostoma* Sauvage.

ancestral stock but diverged from each other at a very early stage, the former being now less specialized than the latter. Both the genera are devoid of any rostral groove.



TEXT-FIG. 2. Ventral surface of head and anterior part of body of *Liniparhomaloptera* Fang and *Parhomaloptera* Vaillant. (After Fang.)
A. Liniparhomaloptera Fang; *B. Parhomaloptera* Vaillant.

After examining specimens of *Crossostoma* in various Natural History Museums of the U.S.A., I (1950) am now of the opinion that there are only two known species in the genus, *C. davidi* Sauvage and *C. fascicauda* Nichols. *C. stigmata* Nichols and *C. tinkhami* Herre seem to be synonymous with *C. fascicauda*. There is con-



TEXT-FIG. 3. Mouth and associated structures of *Crossostoma* Sauvage.
A. Crossostoma davidi Sauvage; *B. Crossostoma fascicauda* Nichols.

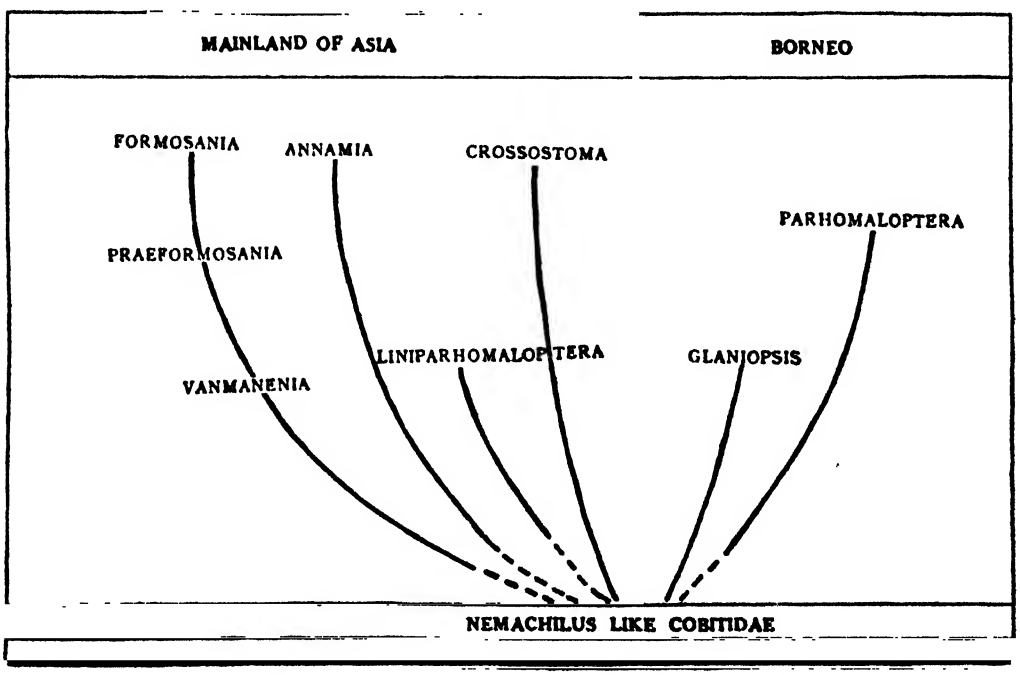
siderable confusion between these two species also. After examining a large amount of material in the American Museum of Natural History, I was able to distinguish them by their colouration, relative extent of pelvic fins, size of the eye and position and size of rostral barbels. Tchang (1932) described *C. fascicauda foochowensis*, but Fang (1935, p. 89) considered it a synonym of *C. davidi*.

I agree with Fang that *Vanmanenia* Hora, *Praeformosania* Fang and *Formosania* Oshima form an evolutionary series of progressive specialisation. All the genera are provided with a rostral fold and a rostral groove. I do not agree with Fang that *Crossostoma* represents the most specialized member of this series. Probably he has been led to this conclusion by wrongly referring *C. fascicauda* to

TEXT FIG. 4. Mouth and associated structures of *Formosania* Oshima.

the genus *Formosania*. In the broad rostral groove of *Formosania*, there are three barbels with broad bases which are placed across the groove and join the anterior lip with the rostral fold, reminding one of a similar condition in the Gastromyzonid genus *Seutellia* Hora. There is nothing of this nature in *Crossostoma fascicauda*. In describing *Vanmanenia* in 1932, I showed its relationships to *Formosania* and indicated that some intermediate form will be discovered. *Praeformosania* now bridges the gulf between the two genera, though it is much closer to *Formosania* than to *Vanmanenia*.

The relationships of the Crossostomid fishes can be represented as shown below:



TEXT-FIG. 5. Probable lines of evolution of the Crossostomid fishes on the mainland of Asia and in Borneo.

It is presumed from the above discussion that the Crossostomid fishes not only evolved independently in Borneo and on the mainland of Asia, but on the mainland they evolved independently at least along four lines and in Borneo along two lines. The basic stock in all cases seems to have been provided by the Cobitid loaches of the *Nemachilus*-type.

Summary.

Morphological and Palaeogeographical evidences all point to the conclusion that the Crossostomoid fishes, like the Gastromyzonid fishes, evolved independently both in Borneo and on the mainland of Asia from primitive cobitid loaches of the *Nemachilus*-type. Further, in the mainland they seem to have evolved independently along four lines and in Borneo along two lines.

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FURTHER STUDIES REGARDING HORA'S SATPURA HYPOTHESIS.

2. Taxonomic Assessment and Levels of Evolutionary Divergences of Fishes with the so-called Malayan Affinities in Peninsular India.

By E. G. Silas, *M.A., M.Sc., Research Fellow, N.I.S.I., from the Laboratories of the Zoological Survey of India.*

(Communicated by Dr. S. L. Hora, D.Sc., F.N.I.)

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Introduction.

Since the enunciation of the Satpura Hypothesis (Hora, 1937), much work has been done on the biogeography of India. Recently a Symposium was held under the auspices of the National Institute of Sciences of India on the 'Satpura Hypothesis of the Distribution of Malayan Fauna and Flora to Peninsular India', (Hora, *et al.*, 1949) containing contributions from different sciences, such as, Geology, Meteorology, Botany and Zoology. In a review of this Symposium, Dr. Ernst Mayr (1950, p. 363) stated that:

> "The members of the Malayan fauna isolated on the Indian Peninsula indicate various levels of evolutionary divergence, ranging from endemic species to subspecific identity. A more complete analysis may shed further light on the period of immigration".

In a letter to Dr. Hora, he also suggested that the Hypothesis be tackled from three other aspects (*vide* Hora, 1951, p. 437). The first of these, namely, the possibility of dispersal of torrential fauna in spite of the existence of the Garo-Rajmahal Gap has been further elucidated by Hora (*loc. cit.*). Menon (1951) investigating the third problem, namely, the possibility of the Eastern Ghats acting as an alternative route of migration, found after a detailed study of the fish fauna of the Eastern Ghats and the Orissa Hills, that there were no typical representatives of the so-called Malayan element there.

The present communication deals with Dr. Mayr's second suggestion, namely, a taxonomic assessment of the fishes with the so-called Malayan affinities in Peninsular India and their different levels of evolutionary divergence. Peninsular India

TABLE 1.

I	II								III
List of genera and species with the so-called Malayan affinities restricted to Peninsular India.	Occurrence of forms showing affinities to the genera and species listed in the first column.								Remarks amplifying the statement made in the second column.
	1	2	3	4	5	6	7	8	
Family CYPRINIDAE									
Osteochilus Günther	—	x	x	x	x	x	x	x	*Osteochilus* has differentiated into subgenera in South China and in Peninsular India (Hora, 1942, p. 7). Typical *Osteochilus* is now found in Thailand, the Malaya Peninsula and the Indo-Australian Archipelago. Of the three Peninsular species, *O.* (*Kantaka*) *brevidorsalis* is known from the central division of the Western Ghats and *O.* (*Osteochilichthys*) *nashii* from the northern and central divisions. *O.* (*Osteochilichthys*) *thomasii* is known from the central and southern divisions (Silas, 1950).
O. (*Osteochilichthys*) *thomassi* (Day) ..	—	—	—	—	—	—	—	—	
O. (*Osteochilichthys*) *nashii* (Day) ..	—	—	—	—	—	—	—	—	
O. (*Kantaka*) *brevidorsalis* (Day) ..	—	—	—	—	—	—	—	—	
Schismatorhynchus Bleeker	—	—	—	—	—	—	—	x	*Schismatorhynchus* of Peninsular India is sub-generically different from the Indo-Australian form, *S.* (*Schismatorhynchus*) *heterorhynchus* Bleeker, (*vide* Hora, 1942).
S. (*Nukta*) *nukta* (Sykes)	—	—	—	—	—	—	—	—	
Rohtee Sykes	—	x	x	—	x	x	x	x	*Rohtee* (*sensu stricto*) is restricted to Peninsular India. The Burmese, Thailand and Malayan forms of *Rohtee* are sub-generically different and are here grouped under the subgenus *Mystacoleucus* (*vide* note on page 8).
R. (*Rohtee*) *ogilbii* Sykes	—	—	—	—	—	—	—	—	
Puntius Hamilton	x	x	x	x	x	x	x	x	*Puntius sarana*, a widely distributed species, has diverged in Southern Burma into a subspecies, *binduchitra* and in Peninsular India and in Malay Peninsula into a closely allied geographical race, *pinnauratus* (Pillay, 1951).
P. sarana Hamilton	x	x	—	—	x	x	x	—	
P. ticto Hamilton	x	x	—	—	—	—	—	—	*Puntius ticto*, has diverged in Peninsular India into a subspecies, *punctatus*, and in Burma into another closely allied subspecies, *stoliczkanus*. (*Vide* note on page 431).
Tor Hamilton	x	x	—	—	x	—	—	—	*Tor mosal* is known from Burma and the Himalayan streams (Hora, 1940). Recently a variety of this species (David, 1952. Seen in MSS.) was discovered from the upper reaches of the Mahanadi. Further west it is replaced by *Tor khudree* (Sykes), which is also found in Ceylon.
T. mosal Hamilton	x	—	—	—	—	—	—	—	

Acrossocheilus Oshima	x	x	x	x	x	x	x	x	Though *Acrossocheilus hexagonolepis* has been recorded from South India by several workers, the precise systematic position of the Peninsular form still remains to be investigated. It will, therefore, not be included in the discussion here.
A. hexagonolepis (McClelland)	x	?	—	—	?	?	?	?	
Osteobrama Heckel	x	x	x	x	x	—	—	—	In either extremity of its range of distribution *Osteobrama cotio* has given rise to two closely allied geographical races, *O. cotio cunma* in Burma, and *O. cotio* var. *peninsularis*, nov. in Peninsular India (*vide* note on page 432).
O. cotió Hamilton	x	x	—	—	x	—	—	—	
Labeo Cuvier	x	x	x	x	x	x	x	x	*Labeo dero* and *Labeo dyocheilus* are known from the Sind Hills, all along the Himalayas, Assam and Burma. The latter has also been recorded from Thailand (Smith, 1945). The recent record of these two species from the Mahanadi and Damodar rivers (David, *loc. cit.*), west of the Garo-Rajmahal Gap is of interest.
L. dero (Hamilton)	x	x	—	—	x	—	—	—	
L. dyocheilus (McClelland)	x	x	—	—	x	x	—	—	
L. (*Morulius*) prox. *chrysophekadion* (Bleeker)	—	—	—	x	—	x	—	x	*Labeo* (*Morulius*) *chrysophekadion* is known elsewhere from Thailand, Indo-China and the Indo-Australian Archipelago. The Peninsular specimens show slight variations from the Thailand forms, but for want of material for comparison, details have not yet been worked out.
Crossocheilus van Hasselt	x	x	x	?	x	x	x	x	*Crossocheilus latius* occurs in the Bombay Ghats portion of the Western Ghats, Kaimur Hills and Chota Nagpur plateau on the Vindhya Satpura trend and the Eastern Himalayas. Its distribution throws light as to the route of migration of the freshwater fishes from the Assam Himalayas to the Peninsula.
C. latius (Hamilton)	x	x	—	—	x	—	—	—	
Garra Hamilton	x	x	x	x	x	x	x	x	*Garra gotyla* is known from the region of the Eastern Himalayas, the Rajmahal Hills (Hora, 1938) and from Hoshangabad in the Satpuras (Hora and Nair, 1941). Like the preceding species, its distribution along the northern parts of the Peninsula is of interest, for it indicates the probable route of migration of freshwater fishes to the Peninsula.
G. gotyla (Gray)	x	—	—	—	—	—	—	—	
Thynnichthys Bleeker	—	—	—	—	—	x	x	x	*Thynnichthys* is represented in Thailand, Malaya Peninsula and the Indo-Australian Archipelago by one species, *T. thynnoides* Bleeker. The Peninsular species, *T. sandkhol* is known from the Godaveri and Kistna river systems (Hora, 1949, p. 412).
T. sandkhol (Sykes)	—	—	—	—	—	—	—	—	

TABLE 1—*Contd.*

I	II								III
List of genera and species with the so-called Malayan affinities restricted to Peninsular India.	Occurrence of forms showing affinities to the genera and species listed in the first column.								Remarks amplifying the statement made in the second column.
	1	2	3	4	5	6	7	8	
Family PSILORHYNCHIDAE									
Psilorhynchus McClelland	x	—	—	—	—	—	—	—	*Psilorhynchus sucatio* is known from the region of the Eastern Himalayas and Northern Burma. David (*loc. cit.*) records a new geographical race of this species from the Damodar river. Being only racially different from its eastern ally, the Damodar form seems to be a recent isolate in the Peninsula.
P. sucatio Hamilton	x	—	—	—	—	—	—	—	
Family HOMALOPTERIDAE									
Homaloptera van Hasselt	—	x	—	x	x	x	x	x	*Homaloptera* is represented in Peninsular India by a single species, while the genus has a wide range of distribution in the east. The two genera *Bhavania* and *Travancoria* which are endemic in the Peninsula, have evolved from the *Homaloptera*-stock. *Balitora brucei* of the Eastern Himalayas has one geographical race in Peninsular India and two very closely-allied races in Burma. For the distributional significance and affinities of the Homalopterid fishes reference may be made to Silas (1952).
H. montana Herre	—	—	—	—	—	—	—	—	
Bhavania Hora	—	—	—	—	—	—	—	—	
B. australis (Jerdon)	—	—	—	—	—	—	—	—	
Travancoria Hora	—	—	—	—	—	—	—	—	
T. jonesi Hora	—	—	—	—	—	—	—	—	
Balitora Gray	x	x	—	—	—	—	—	—	
B. brucei var. *mysorensis* Hora	—	—	—	—	—	—	—	—	
Family SCHIZOTHORACINAE									
Lepidopygopsis Raj	x	x	x	—	—	—	—	—	The Schizothoracine genus *Lepidopygopsis* Raj (1941) which is endemic in the Peninsula (Periyar Lake, Travancore) has its nearest related forms in *Schizothorax* and *Oreinus* which are mainly Central Asiatic in distribution though a few species are found in the Himalayas and South-Western China. For further information reference may be made to Hora (1949, p. 411).
L. typus Raj	—	—	—	—	—	—	—	—	
Family SCHILBEIDAE									
Silonia Swainson	x	x	—	—	x	—	—	—	*Silonia silondia* of Northern India and Burma is also known from the Cauvery watershed in the Peninsula. In the south it seems to have diverged into another species, *S. childreni* (*vide* note on page 433). *Pangasius pangasius* is another species which
S. childreni (Sykes)	—	—	—	—	—	—	—	—	
S. silondia (Hamilton)	x	x	—	—	x	—	—	—	
Pangasius Valenciennes	x	x	—	x	x	x	x	x	
P. pangasius (Hamilton)	x	x	—	—	x	x	x	x	

										shows discontinuous distribution for it is known from the Cauvery watershed in Peninsular India and further east from North-Eastern India, Burma, Thailand, Malaya and Java.
Eutropiichthys Bleeker	..	..	x	x	—	—	x	—	—	—	Hora (1937, pp. 431–445) elucidated the status of the species of *Eutropiichthys* Bleeker. The Peninsular isolate, *E. goongwaree* seems to have diverged from the widely distributed from *E. vacha* (Hamilton).
E. goongwaree (Sykes)	..	..	—	—	—	—	—	—	—	—	
Neotropius Kulkarni	..	..	x	x	—	—	x	x	x	x	Kulkarni (1951, seen in MSS.) describes a new monotypic Schilbeid genus from Satara District in Bombay Presidency. This form shows great affinity to *Pseudeutropius acutirostris* Day and seems to have diverged in Peninsular India from *Pseudeutropius*-like forms.
N. khavalchor Kulkarni	..	..	—	—	—	—	—	—	—	—	
Family BAGRIDAE											
Batasio Blyth	..	..	x	x	—	—	x	x	—	—	*Batasio travancoria* Hora and Law (1941) is so far known from the southern division of the Western Ghats in the Peninsula. Hora (1949, p. 414) has commented on the discontinuous distribution of the genus. The recent record of *Batasio tengana* from the Mahanadi river by David (*loc. cit.*), extends the distribution of the genus from the region of the Eastern Himalayas to the northern parts of the Peninsula.
B. travancoria Hora & Law	..	..	—	—	—	—	—	—	—	—	
B. prox. *tengana* (Hamilton)	.	..	x	x	—	—	x	x	—	—	
Pseudobagrus Bleeker	..	..	—	—	x	x	—	—	—	—	Besides Malabar in Peninsular India, *Pseudobagrus* is elsewhere known from China. This marked discontinuous distribution of the genus is of considerable zoogeographical significance.
P. brachysoma Günther	..	..	—	—	—	—	—	—	—	—	
Family SISORIDAE											
Gagata Bleeker	..	..	x	x	—	—	x	x	—	x	The genus *Gagata*, which is found along the Eastern Himalayas, Burma, Thailand and Sumatra is represented in the central and northern division of the Western Ghats by one species, *G. itchkeea* (Sykes). Two other species, *G. cenia* and *G. gagata* which are mainly distributed along the Himalayas is also found in certain places along the Vindhya Satpura trend. They are taxonomically identical with the Eastern Himalayan population. Their absence in the Peninsula proper suggest that they are recent isolates in the northern parts of the Peninsula and have not diverged so far.
G. itchkeea (Sykes)	..	..	—	—	—	—	—	—	—	—	
G. cenia (Hamilton)	..	..	x	x	—	—	x	x	—	—	
G. gagata (Hamilton)	..	..	x	x	—	—	x	x	—	—	

TABLE 1—*Contd.*

I	II								III
List of genera and species with the so-called Malayan affinities restricted to Peninsular India.	Occurrence of forms showing affinities to the genera and species listed in the first column.								Remarks amplifying the statement made in the second column.
	1	2	3	4	5	6	7	8	
Glyptothorax Blyth	x	x	x	?	x	x	x	x	The Eastern Himalayan form *Glyptothorax horai* was recorded from the Rihand by Hora (1949). Its occurrence in this watershed draining part of the Vindhya Satpura trend and separated from the Eastern Himalayas is yet another instance to show the probable route of migration of fresh-water forms to the Peninsula.
G. horai Shaw and Shebbeare	x	—	—	—	—	—	—	—	
G. annandalei Hora	x	—	—	—	—	—	—	—	Menon (1949, p. 237) recorded *Glyptothorax annandalei* from the Kosi river in the Eastern Himalayas. The species is also known from the Vindhyas and the northern and central parts of the Western Ghats.
Erethistoides Hora	x	—	—	—	—	—	—	—	A geographical race of the Assam form *Erethistoides montana, var., pipri* was described from the Rihand by Hora (1949). Thus as in the case of *G. horai* the distribution of the genus is of zoogeographical importance.
E. montana var. *pipri* Hora	—	—	—	—	—	—	—	—	
Laguvia Hora	x	—	—	—	—	—	—	—	The occurrence of *Laguvia ribeiroi* in Hoshangabad District on the Vindhya Satpuras (Hora and Nair, 1941), and the Rihand (Hora, 1949) is of distributional significance, for it is elsewhere known from the Tista river (Jalpaiguri District), in the Eastern Himalayas.
L. ribeiroi Hora	x	—	—	—	—	—	—	—	
Family AMBLYCEPIDAE									
Amblyceps Blyth	x	x	—	—	x	x	x	—	The occurrence of *Amblyceps mangois* in Hoshangabad District on the Vindhya Satpuras (Hora and Nair, 1941) and the Rihand, Mahanadi and Rajmahal Hills west of the Garo-Rajmahal Gap is of considerable interest as showing the probable continuity of the Satpura trend of mountains with the hills of Assam and Darjeeling Himalayas. *A. mangois* is also found along the Himalayas, hills of Assam, Burma, Thailand and Malaya Peninsula.
A. mangois (Hamilton)	x	x	—	—	x	x	x	—	
Family SILURIDAE									
Silurus Linnaeus	x	x	x	x	x	x	x	—	*Silurus* seems to have diverged in Peninsular India

S. goae Haig	—	—	—	—	—	—	—	—	both into a species and a subspecies. *S. goae* Haig is specifically different from *S. berdmorei wynaadensis* which has its nearest related form in *S. berdmorei berdmoeri* of Akyab in Burma. All these forms are allied to the widely distributed *S. cochinchinensis* Cuv. & Val. (*vide* note on page 433).
S. berdmoeri var. *wynaadensis* (Day) ..	—	—	—	—	—	—	—	—	
S. cochinchinensis Valenciennes	x	x	x	x	x	x	—	—	
Family Clariidae									
Clarius Gronovius	x	x	x	x	x	x	x	x	*Clarias dussumieri*, *C. dayi* and *C. brachysoma* of Peninsular India and Ceylon resemble *C. meladerma* and *C. teysmanii* of the Malayan region. Their close similarity suggest a common origin for the Peninsular Indian and the Malayan forms (*vide* note on page 434).
C. dussumieri var. *dussumieri* Cuv. & Val. ..	—	—	—	—	—	—	—	—	
C. dussumieri var. *dayi* (Hora)	—	—	—	—	—	—	—	—	
C. dussumieri var. *brachysoma* (Günther)* ..	—	—	—	—	—	—	—	—	
Family Pristolepidae									
Pristolepis Jerdon	x	x	—	x	x	x	x	x	The two Malabar forms *P. marginatus marginatus* and *P. marginatus malabaricus* seem to have diverged from the widely distributed form *P. fasciatus* (*vide* note on page 435).
P. marginatus var. *marginatus* Jerdon ..	—	—	—	—	—	—	—	—	
P. marginatus var. *malabaricus* (Günther) ..	—	—	—	—	—	—	—	—	
P. fasciatus (Bleeker)	x	x	—	x	x	x	x	x	
Family Symbranchidae									
Amphipnous Muller	x	—	—	—	—	—	—	—	Recently Krishnan Nair (1951) described a new species of *Amphipnous*, *A. fossorius* from Southern Travancore in the Peninsula. The other species of *Amphipnous*, *viz.*, *A. cuchia* is found in North-Eastern India and Burma.
A. fossorius Nair	—	—	—	—	—	—	—	—	
Family Tetraodontidae									
Tetraodon (*Monotretus*) *travancoricus* Hora & Nair.	x	x	—	—	x	—	—	—	*Tetraodon* (*Monotretus*) *travancoricus* has its nearest ally in *T.* (*Monotretus*) *cutcutia* of North Eastern India and Burma. (Hora and Nair, 1941).

* Found in Ceylon.

is considered here as the triangular Plateau lying south of the Indo-Gangetic alluvium and extending to the north-east as far as the Rajmahal Hills.* In his revision of the Indian freshwater fishes, Dr. Hora has clarified the taxonomic position of many of the Peninsular representatives, but still there remain a number of species with Malayan affinities, the taxonomy of which need further elucidation. It is, therefore, proposed to deal with the taxonomic assessment of the species before discussing their evolutionary divergences.

Table showing the list of species with the so-called Malayan Affinities in Peninsular India.

In the following table (Table 1) are listed all important Peninsular genera and species of fishes showing Malayan affinities. This table also indicates the eastern affinities of the forms now restricted to the Peninsula. In the remarks column, references are made to previous important works on their taxonomic and zoogeographical aspects. The species, whose taxonomic status needs further elucidation, are dealt with separately in the next section of the paper.

In column two of the following table the localities are arranged as follows: (1) Eastern Himalayas, (2) Northern Burma, (3) Yunnan and Southern China, (4) Indo-China, (5) Lower Burma, (6) Thailand, (7) Malaya Peninsula, and (8) Indo-Australian Archipelago. The distribution of the genera in the above areas and that of the Peninsular isolates are also indicated in this column.

Taxonomic Assessment of certain forms.

Rohtee Sykes.

Sykes (1841), in erecting the genus *Rohtee* for three species from Peninsular India, did not denote any one of them as the type of his new genus. Jordan (1919) named *R. nigorsii* Sykes as the orthotype of the genus *Rohtee* and this was adopted by later workers, like Mukerji (1934), Hora (1940) and Smith (1945). Smith, however, stated that 'the first designation of the type of *Rohtee* was by Bleeker (1864, 314), 'when *R. ogilbii* was definitely selected'.

R. ogilbii Sykes, on account of the presence of a procumbent predorsal spine was placed under the genus *Mystacoleucus* Günther by Hora (1940). But since Bleeker had already designated *R. ogilbii* as the type of *Rohtee*, it is only proper, that, species now assigned to *Mystacoleucus* (forms with procumbent predorsal spine) be placed under *Rohtee*. With this nomenclatorial change, the species other than *ogilbii*, which are included under *Rohtee* (Hora, 1940), have to take another generic name, and the use of *Osteobrama* Heckel for them is considered valid.

Thus, *Rohtee* which is characterised by the presence of a procumbent predorsal spine is represented in Peninsular India on the one hand and Lower Burma, Thailand, Malaya Peninsula and the Indo-Australian Archipelago on the other. The Chinese species with procumbent predorsal spine were grouped under the genera *Spinibarbus* Oshima and *Spinibarbichthys* Oshima. For a satisfactory classification of *Rohtee*, it has been found necessary to split up the genus into two subgenera, both on taxonomic as well as on geographical grounds. The type species, *R. ogilbii* of Peninsular India, which is geographically widely separated from the other species and also differs considerably from the rest in the number of lateral line scales and the anal rays is considered in this revision as *Rohtee* (*sensu stricto*). All the remaining species are grouped under *Mystacoleucus*, which is

* The Shillong Plateau in Assam is only a severed portion of the Peninsula which has been isolated by the alluvium of the lower Ganges and Brahmaputra.

regarded here as a subgenus of *Rohtee*. The known species of *Rohtee* and their range of distribution are given below:

Rohtee (*Rohtee*) *ogilbii* Sykes ..	Deccan, Peninsular India.
Rohtee (*Mystacoleucus*) *argenteus* (Day)	Burma.
Rohtee (*Mystacoleucus*) *marginatus* Valenciennes	Lower Burma, Thailand, Malaya Peninsula and the Indo-Australian Archipelago.
Rohtee (*Mystacoleucus*) *chilopterus* Fowler	Thailand.
Rohtee (*Mystacoleucus*) *atridorsalis* Fowler	Thailand.
Rohtee (*Mystacoleucus*) *padangensis* (Bleeker)	Sumatra.

Puntius ticto Hamilton.

Day (1878) gave the range of distribution of *Puntius ticto* as, 'Sind, throughout India and Ceylon', and recognised two other closely related species, *viz.*, *Puntius punctatus* in Peninsular India and *Puntius stoliczkanus* in Burma. Regarding the latter he observed:

> 'This species bears a strong resemblance to *B. ticto* H.B., which it appears to supersede in Burma. But it is distinguished by a complete instead of an incomplete lateral line, and its body is not so compressed; its dorsal spine and colouring also differ.'

Smith (1945) also remarked on the great similarity of *P. stoliczkanus* to *P. ticto*. Hora, Misra and Malik (1939), who studied the variations in *Puntius ticto*, assigned *P. punctatus* and *P. stoliczkanus* to its synonymy, as they found it difficult to separate the Peninsular and the Burmese forms from *P. ticto* specifically. They also stated that:

> 'In studying several collections of freshwater fishes from India and Burma, Hora found considerable variation in specific characters usually relied upon for the determination of Hamilton's *Cyprinus* (*Puntius*) *ticto*. Though he recently made an attempt to give the diagnostic features of *Barbus* (*Puntius*) *stoliczkanus* Day, a form closely allied to *B. ticto*, a collection from Dalu, in the Upper Chindwin Drainage showed that these characters were not of much use in separating the two species. Moreover, the specimens of *B. ticto* from Peninsular India were found to exhibit gradations between the two forms, while Day's *B. punctatus* from South India appeared to be identical with the Burmese *B. stoliczkanus*.'

The morphometric data that they gave for a number of specimens of *Puntius ticto* from different localities along its range of distribution has been of considerable help in redefining the present limits of the species. When the characters of *P. ticto* are taken as a whole, they seem to be highly variable and overlapping, thus forming more or less a mix up. But as in the case of *Puntius sarana* Hamilton, (Pillay, 1951) certain characters in *P. ticto* are also more predominant and well defined in some areas than in the others. Both marked qualitative and quantitative variations are present towards either extremity of its range of distribution. Taxonomically as well as on geographical grounds, such localised conditions or divergences from the typical form would entail the institution of separate species, subspecies or races, for such forms. But these divergences of

P. ticto in Peninsular India and Burma do not seem to be of specific levels, as can be noted from the following table:

Puntius ticto punctatus (Day).	*Puntius ticto ticto* Hamilton.	*Puntius ticto stoliczkanus* (Day).
Lateral line complete ..	Lateral line incomplete (perforated scales 6–16).	Lateral line complete.
P.15; L.1.23–24 ..	P.15; L.1.23–26 ..	P.14; L.1.25.
Predorsal scales 8 ..	Predorsal scales 11 ..	Predorsal scales 8–10.
3 rows of scales between lateral line and pelvics.	4–5 rows of scales between lateral line and pelvics.	3½ rows of scales between lateral line and pelvics.
Distribution: Malabar and Coromandel coast, Peninsular India.	Throughout Ceylon, India and Burma.	Lower Burma and Thailand.

On these grounds it has been found necessary to resurrect the names *punctatus* and *stoliczkanus*, and they are treated as subspecies of *Puntius ticto*, which has a wide range of distribution, being found in Ceylon, India and Burma. However, it is interesting to note that both in Peninsular India on the one hand and in Burma and Thailand on the other, *P. ticto* has diverged almost along similar lines.

Osteobrama Heckel.

Of the species of *Osteobrama* at present known from India, Burma, Southern China (Yunnan) and Indo-China, *O. cotio* (Hamilton) is of considerable interest, for this species seems to have diverged both in Peninsular India and in Burma into two geographical races. Earlier workers considered the Peninsular and Burmese forms as one and the same variety of *cotio*, namely, *O. cotio* var. *cunma* (Day). In stating the affinities of this form with the *forma typica*, Hora and Misra (1940) observed:

> 'It differs from *Rohtee cotio* in having somewhat larger and more regularly arranged scales (L.1.42–58 *versus* 57–70), predorsal scales 18–24 *versus* 24–28; between lateral line and pelvics 7½–9½ *versus* 10½ to 13 and fewer rays in the anal fin (28–34 *versus* 31–36). In all other respects, except that the variety *cunma* probably grows to somewhat larger size, the two forms are very similar and there seems no doubt that they must have become differentiated not very long ago.'

Vinciguerra (1890) recognised Valencienne's *R. alfrediana* as a distinct species in Burma. The variety *cunma* was described by Day (1878) from specimens collected from Burma. Hora and Misra (*op. cit.*) clarified the status of *alfrediana*, but they have included the Peninsular species under the variety *cunma*. The morphometric data that they gave of a number of specimens of *cunma* from Burma and Peninsular India shows that the Peninsular and Burmese populations of *cunma* are in fact different to a certain extent. The main variations found between *O. cotio cotio* and the Peninsular and Burmese forms ascribed to *cunma* are tabulated below:

No.	Characters.	*O. cotio* var. (Peninsular India).	*O. cotio cotio*.	*O. cotio cunma* (= *alfrediana*) Burma.
1	No. of scales along L.I. ..	55–60	58–70	42–53
2	No. of predorsal scales ..	21–24	24–29	28–30
3	No. of scales between L.I. and V	7½–9½	10½–13	7½–8½
4	No. of branched anal rays ..	28–31	33–38	25–29

It is seen that the Burmese and Peninsular populations do differ from each other, and as *O. cotio cunma* is already applied to the Burmese forms, the Peninsular variety stands without a name. It is, therefore, proposed to denote the latter here as *Osteobrama cotio* var. *peninsularis*, nov. The new variety may be briefly characterised as follows:

Osteobrama cotio var. *peninsularis*, nov.

D.3/9; P.16; V.1/9; A.3/28–31; C.19; L.l.55–60.

Head contained 3·75 to 4·5 and height of body 2·25 to 2·75 in standard length. Diameter of eye 2·5 to 3 in head. Diameter of eye about that of inter-orbital width. Dorsal commences nearer to tip of snout than to base of caudal. Pectorals reach slightly beyond pelvic origin and pelvics extend up to anal fin. Anal with 28 to 31 branched rays. Scales 55 to 60 along lateral line. $7\frac{1}{2}$ to $9\frac{1}{2}$ scales between lateral line and pelvics. Predorsal scales 21 to 24. The colour in spirit is pale yellowish, the upper half being darker. Fins are unmarked.

The type locality of this new variety is Poona in the Bombay Presidency. A number of specimens from this type locality are present in the collection of the Zoological Survey of India (Indian Museum).

Silonia Swainson.

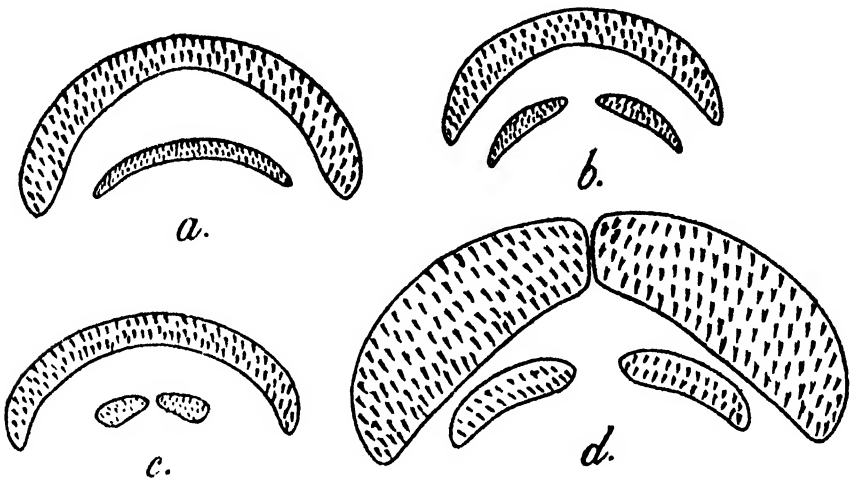
Day (1878) gave the distribution of *Silonia* as 'Estuaries of India and Burma, ascending high up the larger rivers to nearly their sources'. As originally defined *Silonia* possesses two minute barbels and this led Hora (1937) to consider *S. childreni* (Sykes) from Peninsular India with four barbels as falling under a separate genus, *Silonopangasius*. Majumdar (1951) records the presence of four barbels in *Silonia silondia* (Hamilton) in Northern India. In a series of specimens examined by him he found that the mandibulary pair, though present, was embedded in the skin. This being the case, it would seem that the Peninsular forms come within the range of variation of *Silonia* and it has become necessary, therefore, to suppress *Silonopangasius* Hora and treat it as a synonym of *Silonia* Swainson. The two Indian species differ principally by the nature of the air-bladder. It would seem that *S. childreni* of South India has become secondarily specialised owing to the tilting of the Western Ghats and the consequent changes resulting in the rejuvenation of the streams in the Peninsula.

Silurus Linneaus.

Miss Haig (1950), while describing a new species of *Silurus*, *S. goae* from Peninsular India also recognised one other Indian species, *viz.*, *S. cochinchinensis* Valenciennes. On the nature of the barbels Hora (1936) had already recognised two Indian species, *S. wynaadensis* Day and *S. cochinchinensis*, and with the latter he synonymised *S. afgana* Günther, *Silurichthys berdmorei* Blyth, and *Pterocryptis gangetica* Peters. Bhimachar and Rao (1940) considered *S. wynaadensis* to be synonymous with *S. cochinchinensis*.

Blyth's type of *Silurichthys berdmorei* is preserved in the collection of the Zoological Survey of India. From an examination of this specimen, as well as the *Silurus* material in the collection, I am led to conclude that *S. berdmorei* differs from *S. cochinchinensis* both in the nature of the dentition as well as the number of anal rays, but shows great affinities to *S. wynaadensis* of Peninsular India. From the latter it differs only in the nature of the barbels. But this character is very highly variable in many of the Siluroid genera and species, and as such, no great

importance can be attached to it. Therefore, on the nature of the dentition and the number of anal rays, *S. wynaadensis* is considered here as a subspecies of *S. berdmorei* (Blyth). Whether *S. cochinchinensis* co-exists with *S. berdmoeri wynaadensis* (Day) or not can be said only after examining more material of these forms from Peninsular India. A detailed account of the taxonomy of this genus will be discussed in a separate paper.



TEXT FIG. 1. Nature of the dentition in species of *Silurus* Linnaeus.
(*a*) *S. cochinchinensis* Valenciennes. ×5.
(*b*) *S. berdmorei berdmorei* (Blyth). ×5.
(*c*) *S. berdmorei wynaadensis* (Day). ×5.
(*d*) *S. goae* Haig. ×4.

The other Peninsular species, *S. goae* is distinguished from *S. berdmorei* by its much deeper body, more extensive vomerine bands and the maxillary band being divided in the centre.

Clarias Gronovius.

In 1936, Hora discussed the systematic position of the various forms of *Clarias* described from India, Burma and Ceylon and concluded that only three species can be recognised from these regions. They are *Clarias batrachus* (Linneaus) (Ceylon, India, Burma, Malaya Peninsula and Indo-Australian Archipelago); *Clarias brachysoma* Günther (Ceylon) and *Clarias dayi* Hora (Wynaad Hills, Western Ghats). Later, in 1941 he revived the name *C. dussumieri* Cuv. & Val., for specimens from Malabar, South Canara, Goa, Belgaum and Pondicherry and stated:

> 'Except for differences in the nature of the pectoral spine and vomerine teeth and the length of the barbels, *C. dussumieri* is closely related to *C. brachysoma* of Ceylon and *C. dayi* of Wynaad.'

Day (1878) identified a single specimen from Wynaad as *Clarias dussumieri* Cuv. & Val., then known from Malabar and Pondicherry. This specimen formed the type of Hora's species *C. dayi* (Hora, 1941). As the specimens had well-defined teeth on the anterior surface of the pectoral spines, as seen in Bleeker's *C. meladerma* of Malaya Archipelago, Day placed the latter in synonymy of *C. dussumieri*. He expressed doubts regarding the validity of *C. brachysoma* of Ceylon as a distinct

species, and placed it in the synonymy of *C. teysmanni* Bleeker of Malaya Peninsula. Hora and Gupta (1941) drew attention to the variations in the shape of the occipital process of *C. teysmanni* in Malaya which intergrades with the condition seen in *C. brachysoma* of Ceylon. Smith (1945) did not consider *C. brachysoma* as distinct from *C. teysmanni*, for, regarding the distribution of the latter he stated:

> 'This species known also from Ceylon, Malaya, Sumatra, Borneo and Java has a very limited distribution in Thailand.'

Undoubtedly, the great similarity between the Malayan and the Peninsular Indian and Ceylonese forms has given rise to this confusion in the taxonomy of these fishes. Therefore, to clarify this, it would seem best, both from distributional data as well as on the nature of morphological characters to consider the Peninsular Indian and Malayan species showing intra-relationships under two complexes or associations. *C. batrachus* being very widely distributed is not of importance in this taxonomic assessment, and hence is left out. To the remaining Peninsular and Ceylonese species the name *dussumieri* may be applied as it has priority over *brachysoma* and *dayi*. The species recognised in the *dussumieri*-group are:

Clarias dussumieri dussumieri Valenciennes.
Clarias dussumieri dayi (Hora).
Clarias dussumieri brachysoma Günther.

A complete taxonomic assessment of the eastern species, namely, *Clarias meladerma* Bleeker; *C. teysmanni* Bleeker; *C. leiacanthus* Bleeker and *C. macrocephalus* Günther is wanting. The first two species, as already indicated, evince great affinity to the *dussumieri*-group. In case *C. leiacanthus* and *C. macrocephalus* also show great similarity to *meladerma* and *teysmanni*, then all four species may have to be placed under one group or super species, and the name *meladerma* is suggested, as it is the oldest in use.

The intra-relationships of the *dussumieri*-group are considered below. In having a more coarsely serrated spine, somewhat shorter barbels and more obtuse teeth on the palate, *C. dussumieri dussumieri* differs from *C. dussumieri brachysoma* of Ceylon. From *C. dussumieri dayi* it can be separated by its much longer nasal barbels, less molariform teeth and less strongly serrated pectoral spine. It is thus intermediate between *brachysoma* and *dayi*. As in the case of the catfishes of the genera *Erethistes* and *Conta* (Hora, 1951) inhabiting the swift streams of the Eastern Himalayas, the serrations on the outer border of the pectoral spines of *C. dayi* may represent an adaptive modification to help the fish to anchor to the substratum in fast-flowing waters. *C. dussumieri dayi* in which these serrations are well developed, is so far known only from the streams of the Wynaad Hills.

The close similarity of the Malayan and Peninsular Indian species of the genus *Clarias* indicate the possibility of a common ancestral stock for these fishes. At either extremities the genus has proliferated giving rise to a number of similar forms.

Pristolepis Jerdon.

Speaking of the distribution of *Pristolepis*, Day (1878) observed:

> 'Freshwaters of the plains and hills of India, Burma, Siam and Malaya Archipelago; those with villiform teeth in the adult on the vomer appear to belong to India proper (*Paranandus*); those with globular teeth on that bone to Burma and eastwards (*Catopra*).'

The three species recognised by Day were: *P. marginatus* Jerdon from Wynaad Hills, *P. malabaricus* (Günther) from the Western Ghats of Malabar and *P. fasciatus* Bleeker from Burma, Thailand and the Malaya Archipelago. Hora and Law (1941) listed *P. fasciatus* in the fauna of Travancore and gave its distribution as:

'Travancore, Burma, Siam, Malaya Archipelago and Cochin China.' The diagnostic characters of the three species are listed in the following table:

No.	Characters.	*P. fasciatus.*	*P. marginatus.*	*P. malabaricus.*
1	No. of dorsal fin rays ..	12–13/14–15	15–16/11–12	14/12–14
2	No. of pectoral fin rays ..	15	14	14–15
3	No. of anal fin rays	3/8	4/8	3/8
4	No. of lateral line scales ..	26–28	27–30	25–27
5	Vomerine teeth	Globular.	Villiform.	Villiform.

But for the differences in the nature of the dentition, the three species seem to be closely related. *P. marginatus* and *P. malabaricus* are more or less similar and it would not be surprising if a detailed study shows that they are only subspecies or races of one species, *P. marginatus*. From the wide range of distribution of *P. fasciatus* and its occurrence in Peninsular India, it would seem that the other two species of *Pristolepis* in the Peninsula have diverged from *fasciatus*-like forms. In any case their close similarity is remarkable.

Physiographic and Climatic Fluctuations Facilitating Migration.

Recent researches show that the migration of the so-called Malayan stock of fishes to the Peninsula was mainly Pliocene and Post-Pliocene. Hora (1944) drew attention to the possibility of this element having reached the Peninsula in a series of waves of migration. Bhimachar (1945) postulated about four waves of migration of fishes to the Peninsula and Ceylon from the region of the Assam Himalayas. On the basis of the distribution of certain freshwater fishes he divided the Western Ghats into three divisions, namely, a northern division comprising the Deccan Trap area from the Tapti river down to 16°N. Latitude about the level of Goa; a central division, extending from 16°N. Latitude southwards and including the Malnad parts of Mysore State, Coorg, Wynaad and parts of South Canara District and the Nilgiris; and a southern division, comprising the Anamalai, Palani and Cardomom Hills of Travancore. That there were a series of influxes from the east may be inferred from the distributional pattern of the Peninsular Isolates (*vide* table on page 438). As it is evident that the greater part of the migration was Post-Pliocene, let us consider what influence the climatic phases of the Pleistocene period would have had on the dispersal of these forms.

In discussing the effects of Himalayan Glaciation on terrestrial and freshwater animal life in Peninsular India, Hora (1949) opined that the 'Refrigeration', though it affected the terrestrial vertebrates, had no direct effect on the aquatic forms. Recently he (Hora, 1951), however, reconsidered this point of view and on the basis of eustatic movements in the sea-level during the Glacial epochs and their effects on physiography and climatology conceded that migration was made possible through consequential changes as a result of glaciation.

Though opinion still differs as to the Plio-Pleistocene boundary, the total duration of the Pleistocene and the Holocene is considered by most workers to be about 600,000 years (Holocene about 22,000 years). The Pleistocene was characterised by four main Glacial epochs which were intervened by three inter-glacial periods. The absolute chronology for the Pleistocene for India is still unknown, but De Terra and Patterson (1939) investigating the relative climatic succession of North Western India succeeded in linking river terraces with the moraines of Himalayan Glaciation. The relative duration of the Himalayan Glacial and Inter-glacial periods were given by them, and they also found, that

there existed great correlation in the connection of moraines with the aggradation terraces both in North-Western India and the Alps. Zeuner (1945, p. 273) also commented on these similarities, thereby throwing more light on the assumption that the Glaciation of the Himalayas were more or less contemporary with those of Europe.

The glacial epochs, when compared with that of the interglacials were of a much shorter duration and were experienced in the southerly latitudes as a succession of cold 'Pluvial Periods', which were characterised by low temperature, increased humidity and a fall in sea-level. As stated by Hora (*loc. cit.*), the physiographic changes resulting from a fall in the level of the sea during the 'Pluvial Periods' of the Pleistocene, would have facilitated the migration of even torrential fishes from the region of the Assam Himalayas to the Peninsula across the present-day Garo-Rajmahal Gap.

But succeeding phases of aridity and increased desiccation, which resulted in a rise in the sea-level, consequently not only isolated certain forms, but temporarily would have checked dispersal of freshwater forms from the Assam Himalayas to the Peninsula. Geological evidences show that, even during the long interglacial periods, there were minor cold oscillations accompanied by a drop in sea-level. On the assumption that these minor changes could have affected the physiography of India, it would seem that in addition to the major influxes of freshwater forms to the Peninsula which coincided with the four main Pluvials, the minor cold oscillations could have also made possible a succession of small waves of migration of such species as are usually found at the foot of the hills. The overlapping distribution of the Peninsular Isolates points to such a conclusion.

In this connection, the changes undergone by the drainage system of the Peninsula during the Pliocene and the Pleistocene will have to be considered. Menon (*loc. cit.*), reconstructing the past drainage system of the northern part of the Peninsula, has shown that the Narbada-Tapti which flowed to the west as a single river, had Mahanadi and Godavari as its tributaries till comparatively recent times in geological history. The tilting of the Peninsula during the Pleistocene reversed this drainage system to its present-day pattern. It would seem that the Narbada-Tapti which drained the regions probably as far east as the Assam Himalayas and the whole of the Satpura trend of mountains, could have undoubtedly facilitated the migration of the early 'eastern element' to the Peninsula. Only this could account for the occurrence of widely separated forms like *Silurus*, *Pseudobagrus*, *Lepidopygopsis*, etc., in the southern parts of the Peninsula today. The probable time and significance of the distribution of the different genera are discussed in a later section.

Table showing the range of distribution of the Peninsular Isolates.

The range of distribution of 47 species of Peninsular Isolates along the Vindhya-Satpura trend and the Western Ghats is given in the following table (Table 2). For convenience, the three divisions of the Western Ghats, as given by Bhimachar (*loc. cit.*), are adopted here.

The localities which are indicated by numbers are as follows: (1) Damodar Section; (2) Rihand Section; (3) Mahanadi Section; (4) Narbada-Tapti Section; (5) Northern Division of the Western Ghats; (6) Central Division of the Western Ghats, and (7) Southern Division of the Western Ghats.

From Table 2 the following analysis is made. Of the 16 isolates found in the Southern division of the Western Ghats, 8 are truly endemic, while six are common to the central and one to the northern division. One species, ***Pristolepis fasciatus*** is elsewhere known from Thailand and the Malayan region. In the central division there are 21 isolates, of which five are truly endemic, six extend

TABLE 2.

Table showing the range of distribution of the Peninsular Isolates.

Name of Species.	Localities.						
	1	2	3	4	5	6	7
Osteochilus (Osteochilichthys) thomassi (Day)	—	—	—	—	—	x	x
Osteochilus (Osteochilichthys) nashi (Day)	—	—	—	—	x	x	—
Osteochilus (Kantaka) brevidorsalis (Day)	—	—	—	—	—	x	—
Schismatorhynchus (Nukta) nukta (Sykes)	—	—	—	—	x	x	—
Rohtee (Rohtee) cotio Sykes	—	—	—	—	x	x	—
Tor mosal Hamilton (a new variety)	—	—	x	—	—	—	—
Puntius sarana var. *pinnauratus* (Day)	—	—	—	—	—	—	x
Puntius ticto punctatus (Day)	—	—	—	—	—	x	x
Osteobrama cotio var. *peninsularis* nov.	—	—	—	—	x	—	—
Garra gotyla (Gray)	x	—	x	x	—	—	—
Labeo (Morulius) prox. *chrysophekadion* Bleeker	—	—	—	—	—	x	—
Labeo dyocheilus (McClelland)	x	—	x	—	—	—	—
Labeo dero (Hamilton)	x	—	x	—	—	—	—
Crossocheilus latius (Hamilton)	x	x	x	—	x	—	—
Thynnichthys sandkhol (Sykes)	—	—	—	—	x	—	—
Homaloptera montana Herre	—	—	—	—	—	—	x
Bhavania australis (Jerdon)	—	—	—	—	—	x	x
Travancoria jonesi Hora	—	—	—	—	—	—	x
Balitora brucei var *mysorensis* Hora	—	—	—	—	x	x	—
Psilorhynchus sucatio var.	x	—	—	—	—	—	—
Lepidopygopsis typus Raj	—	—	—	—	—	—	—
Silonia silondia (Hamilton)	—	—	—	—	—	x	—
Silonia childreni (Sykes)	—	—	—	—	x	x	x
Pangasius pangasius (Hamilton)	—	—	—	—	—	x	—
Eutropiichthys goongwaree (Sykes)	—	—	—	—	x	—	—
Neotropius khavalchor Kulkarni	—	—	—	—	x	—	—
Batasio travancoria Hora & Law	—	—	—	—	—	—	x
Batasio prox. *tengana* (Hamilton)	—	—	x	—	—	—	—
Pseudobagrus brachysoma Günther	—	—	—	—	—	x	x
Gagata cenia (Hamilton)	x	x	x	—	—	—	—
Gagata itchkeea (Sykes)	—	—	—	—	x	x	—
Gagata gagata (Hamilton)	—	—	x	—	—	—	—
Laguvia ribeiroi Hora	x	x	x	x	—	—	—
Glyptothorax horai Shaw & Shebbeare	—	x	—	—	—	—	—
Glyptothorax annandalei Hora	—	x	—	—	x	x	—
Erethistoides montana var *pipri* Hora	—	x	—	—	—	—	—
Amblyceps mangois (Hamilton)	x	x	x	x	—	—	—
Silurus goae Haig	—	—	—	—	—	x	x
Silurus berdmorei var *wynaadensis* (Day)	—	—	—	—	—	x	—
Silurus cochinchinensis Valenciennes	—	—	—	—	—	x	—
Clarias dussumieri dussumieri Valenciennes	—	—	—	—	—	x	x
Clarias dussumieri dayi (Hora)	—	—	—	—	—	x	—
Pristolepis marginatus marginatus Jerdon	—	—	—	—	—	x	—
Pristolepis marginatus malabaricus (Günther)	—	—	—	—	—	x	x
Pristolepis fasciatus (Bleeker)	—	—	—	—	—	—	x
Amphipnous fossorius Nair	—	—	—	—	—	—	x
Tetraodon (Monotretus) travancoricus Hora & Nair	—	—	—	—	—	—	x

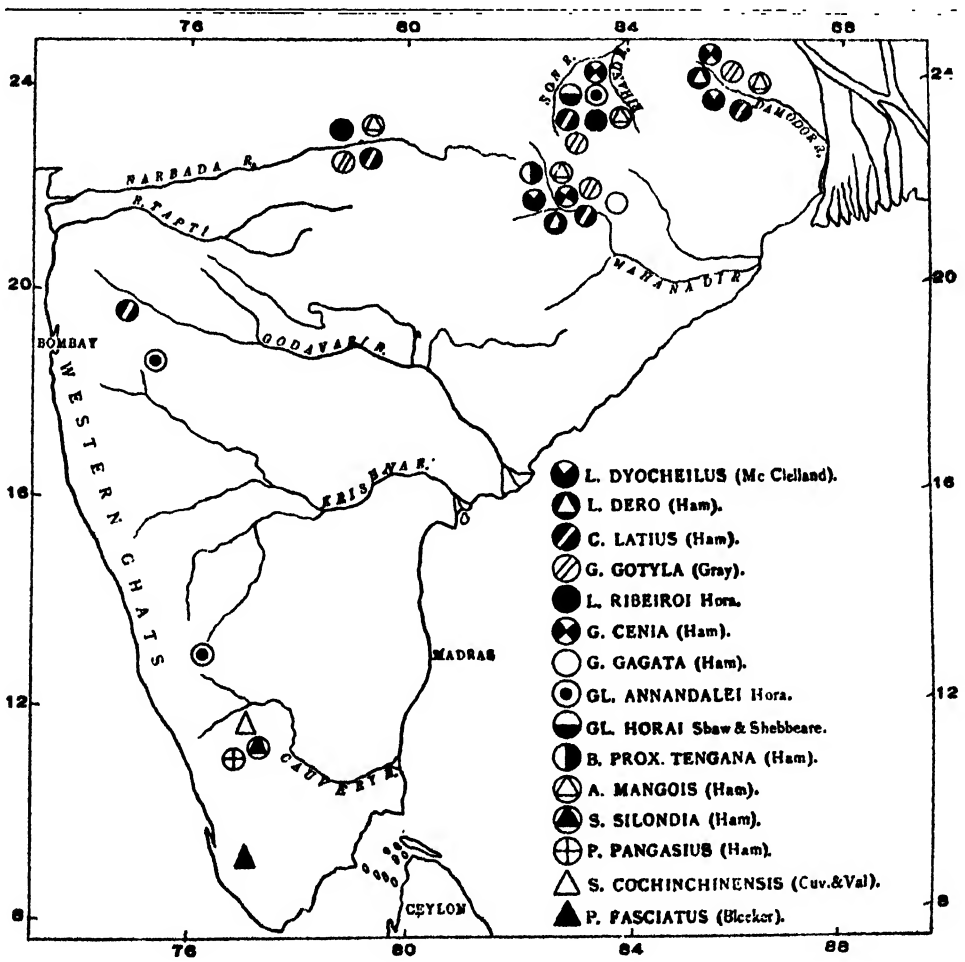
to the southern division, seven to the northern division and one to the Rihand section. The two species *Silonia silondia* and *Pangasius pangasius* are known generally from Northern India and further east. *Silurus cochinchinensis* is elsewhere found in the region of the Eastern Himalayas, Northern Burma, Southern China and Indo-China. In the northern division there are four endemic forms while seven are common to the central and one to the southern divisions; one to the Rihand and one is found all along the Vindhya-Satpura trend. The three isolates found in the Narbada-Tapti section are also found all along the Vindhya

Satpura trend. Of the nine isolates of the Mahanadi section, one is truly endemic, while one is common to the Northern division of the Western Ghats, two to the Narbada-Tapti section, three to the Rihand and six to the Damodar section. In the Rihand section, out of seven isolates, only one is truly endemic, while one is common to the central and northern divisions of the Western Ghats, one to the northern division, two to the Narbada-Tapti section, three to the Mahanadi and four to the Damodar section. Of the eight isolates of the Damodar section, one is truly endemic, while one is common to the northern division of the Western Ghats, three to the Narbada-Tapti and six to the Mahanadi sections.

It will thus be seen that endemicity is more pronounced in the extreme southern section of the Western Ghats below the Palghat Gap and gradually decreases as one goes up along the Ghats and then the Vindhya-Satpura trend of mountains. High endemicity is a clear proof of the longer isolation of the forms in the southern portion of Peninsular India.

Levels of evolutionary divergences.

In order to get a clear understanding of the status of the Peninsular Isolates, the category of species showing a continuous range of distribution, throughout



Text-fig. 2. Outline map of Peninsular India showing the distribution of species which are represented in the Eastern Himalayas, Burma and furthor east by taxonomically identical forms.

India, Burma, Thailand, and further east, such as, *Clarias batrachus*, *Oreichthys cosuatis*, *Danio aequipinnatus*, etc., have not been included in the list. Even in the case of some of these forms the range of distribution is great enough, so that variations correlated with geography could exist, which would probably justify the erection of new races or subspecies. But this would entail a detailed study of the species concerned along its whole range of distribution.

Unlike birds (Ripley, 1949), among fishes the various levels of evolutionary divergences have been of a much greater magnitude, ranging from generic to racial levels. Obviously, the rates of evolution are not the same in all the genera. The forms most affected seem to be the torrential fishes, for being highly specialised, they are likely to become isolated in certain river-systems, as a result of which the rate of speciation is accelerated in them. The different levels of evolutionary divergences of the Peninsular Isolates are given below:

1. Generic Divergence.

Bhavania Hora.
Travancoria Hora.
Lepidopygopsis Raj.
Neotropius Kulkarni.

2. Subgeneric Divergence.

Osteochilichthys Hora.
Nukta Hora.
Kantaka Hora.
Rohtee Sykes.

3. Specific Divergence.

Osteochilus (*Osteochilichthys*) *nashii* (Day).
Thynnichthys sandkhol (Sykes).
Labeo (*Morulius*) prox. *chrysophekadion* Bleeker.
Homaloptera montana Herre.
Silonia childreni (Sykes).

Eutropiichthys goongwaree (Sykes).
Batasio travancoria Hora and Law.

Pseudobagrus brachysoma Günther.
Gagata itchkeea (Sykes).
Silurus goae Haig.

Amphipnous fosserius Nair.
Tetraodon (*Monotretus*) *travancoricus* Hora and Nair.

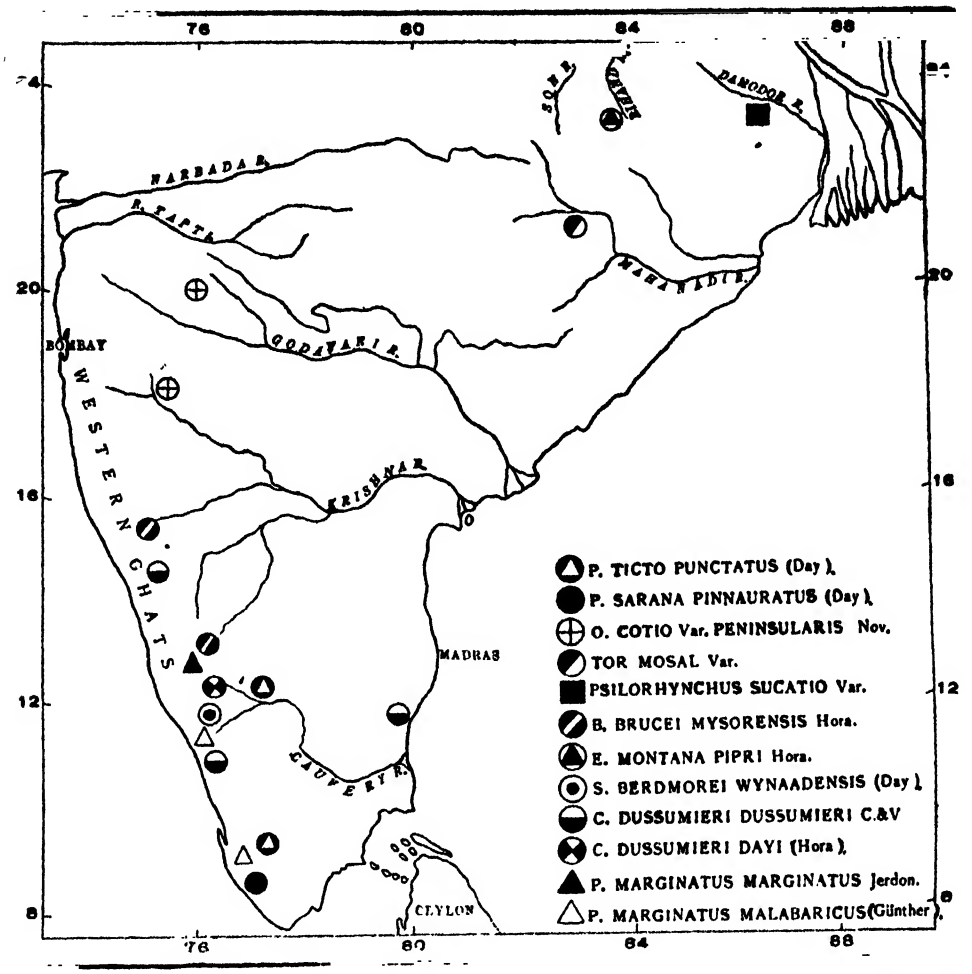
4. Subspecific and Racial Divergence.

Puntius ticto punctatus (Day).
Puntius sarana pinnauratus (Day).

Tor mosal var.
Psilorhynchus sucatio var.
Osteobrama cotio var. *peninsularis*, nov.

Balitora brucei var. *mysorensis* Hora.

Erithistoides montana var. *pipri* Hora.
Silurus berdmorei var. *wynaadensis* (Day).
Clarias dussumieri dussumieri Val.
Clarias dussumieri dayi (Hora).
Pristolepis marginatus marginatus Jerdon.
Pristolepis marginatus malabaricus (Günther).



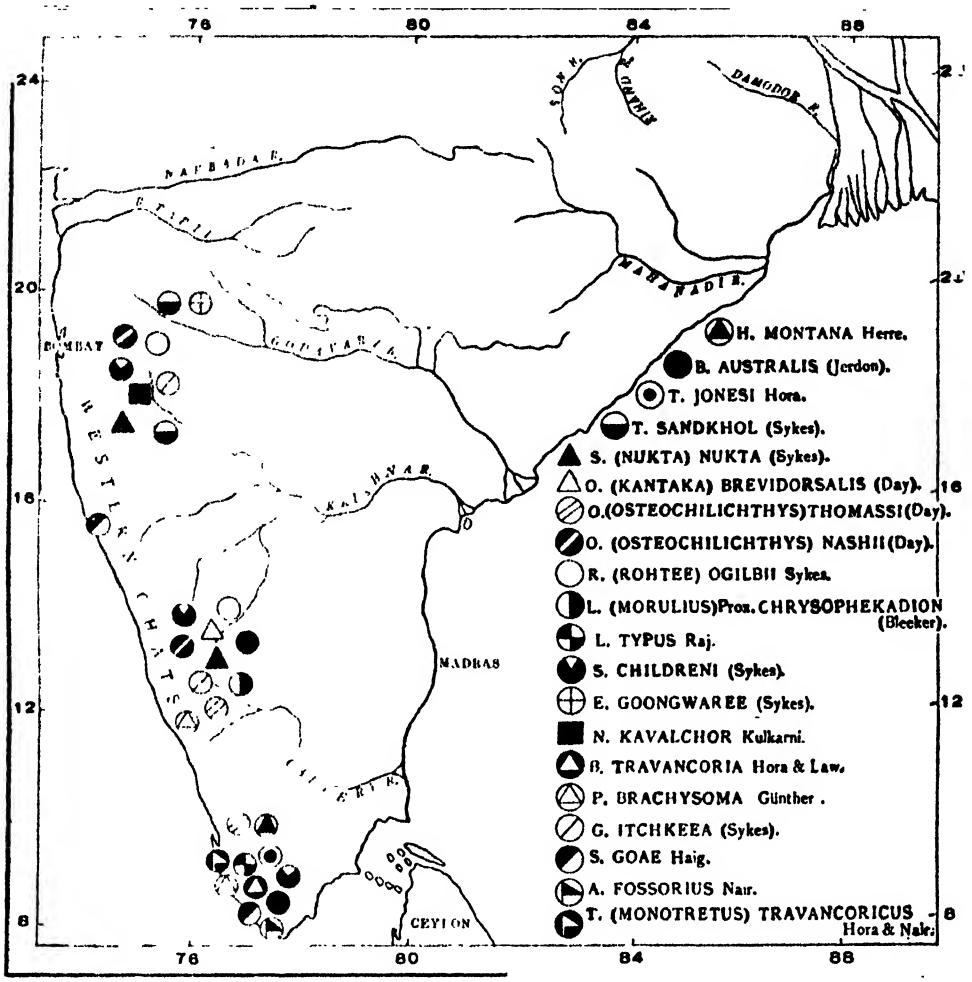
TEXT-FIG. 3. Outline map of Peninsular India showing the distribution of Subspecific and Racial divergents among the Peninsular Isolates with Malayan affinities.

5. Species showing Discontinuous Distribution.

Garra gotyla (Gray).
Labeo dyocheilus (McClelland).
Labeo dero (Hamilton).
Crossocheilus latius (Hamilton).
Batasio prox. *tengana* (Hamilton).
Gagata cenia (Hamilton).
Gagata gagata (Hamilton).
Laguvia ribeiroi Hora.
Glyptothorax horai Shaw & Shebbeare.
Glyptothorax annandalei Hora.
Silonia silondia (Hamilton).
Pangasius pangasius (Hamilton).
Amblyceps mangois (Hamilton).
Silurus cochinchinensis Valenciennes.
Pristolepis fasciatus Bleeker.

The fifteen species included in the fifth category are identical (taxonomically) with the Assam Himalayan and further eastern populations. The approximate percentages of the different levels of divergences of the 47 Peninsular Isolates considered here are given below:

Generic Divergence	8·51%
Subgeneric Divergence	8·51%
Specific Divergence	25·53%
Subspecific and Racial Divergence	25·53%
Percentage of taxonomically identical forms	31·91%



TEXT-FIG. 4. Outline map of Peninsular India showing the distribution of Generic, Subgeneric and Specific divergents among the Peninsular isolates with Malayan affinities.

Table 3 gives the number of isolates and the approximate percentage* of endemicity in each of the sections.

In Table 4 the degree of divergence (in percentage) of the isolates in each section is given. Under 'identical forms' is given the percentage of isolates which are taxonomically identical with the Assam Himalayan and further eastern populations.

As already stated, the greatest amount of divergence and percentage of endemicity is met with in the southern division of the Western Ghats. It is evident that these forms would have been isolated for a considerably longer period than those found in the northern parts of the Peninsula. Only very slight differentiation seems to have taken place along the Vindhya Satpura trend, for a greater part of the species are taxonomically identical with the Eastern Himalayan and further eastern populations. The distribution of forms like *Amblyceps*, *Laguvia*, *Labeo dyocheilus*, *Labeo dero*, *Garra gotyla*, etc., along this trend, but absent in the Peninsula proper, indicate that they are recent isolates and probably represent the last phases of migration.

* The percentage is calculated from the total number of Peninsular isolates considered here which number 47.

TABLE 3.

No.	Particulars.	*Vindhya-Satpuras.*				*Western Ghats.*		
		Damodar section.	Rihand section.	Mahanadi section.	Narbada-Tapti section.	Northern division.	Central division.	Southern division.
1	Total number of species in each section	8	7	9	3	12	22	16
2	Number of truly endemic species ..	1	1	1	..	4	5	7
3	Percentage of species in each section as compared to the total number of Peninsular Isolates ..	17·02	14·89	19·14	6·38	25·53	46·8	34·04
4	Percentage of endemicity in each section as compared to the total number of Peninsular Isolates ..	2·12	2·12	2·12	..	8·51	10·63	14·89

TABLE 4.

Localities.	No. in each section & percentage.	Generic divergence.	Subgeneric divergence.	Specific divergence.	Subspecific or racial divergence.	Identical forms.
DAMODAR SECTION	Number ..	..	..	..	1	7
	Percentage ..	..	..	..	12·5	87·5
RIHAND SECTION	Number ..	..	..	..	1	6
	Percentage ..	..	..	..	14·3	85·7
MAHANADI SECTION	Number ..	..	..	..	1	8
	Percentage ..	..	..	..	11·1	88·9
NARBADA-TAPTI SECTION ..	Number ..	..	..	..	..	3
	Percentage ..	..	..	..	..	100
NORTHERN DIVISION ..	Number ..	1	3	4	2	2
	Percentage ..	8·33	25	33·3	16·66	16·66
CENTRAL DIVISION	Number ..	1	4	6	7	4
	Percentage ..	4·54	18·18	27·27	31·81	18·18
SOUTHERN DIVISION ..	Number ..	3	1	7	4	1
	Percentage ..	18·75	6·25	43·75	25	6·25

The taxonomic assessment of the species show that, both in Peninsular India and Burma and further east, subspecific and racial divergences of Polytypic species such as, *Balitora brucei*, *Puntius sarana*, *Puntius ticto*, and *Silurus berdmorei* have taken place on almost similar lines. These, in addition to the occurrence of species, such as, *Clarias dussumieri*, *Batasio travancoria*, *Gagata itchkeea*, etc., which may be components of different super-species give us some idea as to the probable source from which the Peninsular Isolates were derived.

Factors facilitating fast-rate of speciation among the Peninsular Isolates.

Geographical isolation is recognised as a factor of prime importance in the process of evolutionary divergence. In addition to this, other agents have also been at work, aiding rapid speciation among the Peninsular Isolates. The most important of these are:

(1) The climatic fluctuations during the Pleistocene, and
(2) Changes in the physiography of the Peninsula during the Pleistocene and consequent effects.

Both favourable and unfavourable climatic phases prevailed throughout the Peninsula during the Pleistocene. The increased glaciation of the Himalayas during the Ice-Age considerably lessened the temperature in the Peninsula and as a result more moist conditions prevailed. Consequently, during the 'Pluvial Periods' there was an uninterrupted greater flow of water in the streams and rivers. Succeeding arid climatic phases reversed these conditions and these fluctuations would have also adversely affected the fauna. So far as fish life is concerned, certain physiographic barriers became negotiable during the 'Pluvial Periods' and the 'Arid Periods' isolated faunas on hill tops, thus inducing rapid speciation.

Further impetus to the rate of speciation was added when as a result of scrap-faulting along the West Coast, the tilting of the Peninsula took place. This tilting not only reversed the drainage system, but rejuvenated the streams of the Western Ghats. Such recent and subrecent rejuvenation of tributary streams is known along the Himalayas as a result of intermittent uplift during recent periods. Chibber (1949, p. 23), had adduced evidence to show that during recent and sub-recent periods there were earth movements which rejuvenated the Himalayan streams several times when their vertical corrosion had been stopped. That similar rejuvenation of the streams would have taken place in the Peninsula during the Pleistocene after the tilting is well exemplified by Wadia's account (Wadia, 1944, p. 17) about the irregularities of the 'curve of erosion' of the Peninsular rivers caused by late earth movements. He observed:

> 'It cannot be said, however, that the channels are wholly free from *all* irregularities, for, some of them do show very abrupt irregularities of the nature of *Falls*. Among the best known water-falls of South India are, the Sivasamudram falls of the Cauvery in Mysore, which has a height of about 300 feet, the Gokak falls of the river of that name in Belgaum district, which are 180 feet in height; the 'Dhurandhar' or the falls of the Narbada at Jabalpur, in which though the fall is only 30 feet, the volume of water is large. The most impressive and best known of waterfalls of India are the Gersoppa Falls of the river Sharavati in North Kanara, where the river is precipitated over a ledge of the Western Ghats to a depth of 850 feet in one single fall. The Yenna falls of the Mahableshwar hills descend 600 feet below in one leap, while the falls of Paikara in the Nilgiri Hills descend less steeply in a series of five cataracts over the gneissic precipice. Indeed, it may be said that such falls are more characteristic of Peninsular than extra-Peninsular India and bear evidence of some minor disturbances in a late geological age.'

Whether the tilting of the Peninsula took place as a result of a single disturbance or whether it was intermittent is not definitely known. Whatever may be the case, it would seem that the stock which reached the Peninsula prior to the tilting, or the 'Pre-tilt forms' underwent the greatest amount of divergence, while the 'Post-tilt forms' have differentiated only slightly from the parent stock. It will also be seen that the greatest divergence is found in the extreme south of the Peninsula and to reach that distance these isolates must have reached the Peninsula at a much earlier age than the others. Secondly the divergence is much more marked in the hill-stream forms which were rejuvenated by the physiographic changes of the Peninsula during the Pleistocene.

Probable sequence of migration.

Of the 'Pre-tilt forms', the earliest to reach the Peninsula would have been genera like *Puntius*, *Tor*, *Garra*, *Homaloptera*, *Lepidopygopsis*, *Nemachilus*, *Glyptothorax*, *Silurus*, *Pseudobagrus*, *Clarias*, *Pristolepis*, *Amphipnous*, etc. Their migration to the Peninsula would not have been later than the earliest Pluvial Period during the Lower Pleistocene. In fact, part of the original stock would have come at a still earlier date. Of the above genera, *Puntius*, *Tor*, *Garra*, *Nemachilus* and *Clarias* are found in Ceylon and they extend as far west as Africa. Since its first severance from India during the late Miocene, Ceylon was intermittently connected to the mainland at different times (Jacob, 1949, p. 341). Its last complete disruption from the mainland took place only about 10,000 years back. This being the case, former temporary land connections with the mainland during the 'Pluvial Periods', when the sea-level fell, would have enabled the migration of the Peninsular species to Ceylon as well as to Africa.

Homaloptera has not so far been recorded from Ceylon. I have elsewhere discussed the distributional significance of this form in Peninsular India (Silas, 1951). From the *Homaloptera*-stock which reached the Peninsula during the early 'Pluvial Period', were evolved at a later date two other genera, namely, *Bhavania* and *Travancoria*. This divergence would have taken place consequent to the tilting of the Peninsula which dated probably not later than the earlier part of the Middle Pleistocene.

The distribution of the genus *Silurus* is interesting, for at present it is known to occur in China and along the Trans-Himalayan portion to Asia Minor and Eastern Europe. In the south it has spread to the Eastern Himalayas and to the Peninsula, its westward spread along the Trans-Himalayas would have been of a much earlier date than its migration to Peninsular India. The continuous Narbada-Tapti River of the early Pleistocene which probably drained places as far east as the Assam Hills would have helped in the migration of this form to the Peninsula.

The Schizothoracine genus *Lepidopygopsis* of the Peninsula has its nearest allies in *Schizothorax* and *Oreinus* of the Himalayas and South China. The former to which it evinces greater affinity was probably a widespread genus in the early-Pleistocene Narbada-Tapti River, thus extending to the Peninsula in past ages. On account of long isolation it has evolved into a new genus in the Peninsula, but probably due to lack of large mountain rivers in the Western Ghats has disappeared from the intervening areas.

The spread of *Pseudobagrus* from Southern China to the Peninsula would have been aided considerably by the ancient Narbada-Tapti River.

Forms like, *Osteochilus*, *Schismatorhynchus*, *Rohtee*, *Labeo* (*Morulius*), *Batasio*, *Silonia*, *Neotropius*, and *Tetraodon*, would have reached the Peninsula later, probably during the later part of the Lower Pleistocene. They have spread to the north, central and even southern divisions of the Western Ghats. The early-Pleistocene Narbada-Tapti would have also facilitated the migration of these forms to the Peninsula.

The main tilting of the Peninsula seems to have taken place after their advent. From the distribution of fishes it would seem that this geological event took place probably not later than the earlier part of the middle-Pleistocene. The 'Pre-tilt forms' have generally diverged considerably. The earliest 'Post-tilt forms' would have been species like, *Balitora brucei*, *Silurus berdmorei*, *Thynnichthys*, etc. Mostly racial or subspecific divergence is seen in these forms. Special mention must be made of the distribution of *Thynnichthys*. Though it has only specifically diverged in Peninsular India, the genus as such is an old one. Fossil specimens of *Thynnichthys* have been reported from the Eocene deposits of Java. *Thynnichthys sandkhol* is found in the northern division of the Western Ghats, and as such its spread to the Peninsula would seem to be of a more recent date. *Thynnichthys*, like, *Schismatorhynchus*, *Osteochilus*, *Homaloptera*, etc., indicates that the spread of these forms from the region of Southern China to the Malayan region was much faster and uninterrupted than its spread to Peninsular India.

The differentiation of *Osteobrama cotio*, *Eutropiichthys goongwaree*, etc., would not have been earlier than the upper-Pleistocene. As already stated (*vide supra* p. 442) the distribution of *Amblyceps*, *Laguvia*, *Eristhistoides*, *Tor mosal*, *Psilorhynchus sucatio*, *Garra gotyla*, etc., along the Vindhya Satpura trend, but absent in the Peninsula proper, indicates that they represent the last phases of migration.

Summary.

In connection with Hora's Satpura Hypothesis, Mayr (*loc. cit.*), suggested certain lines of approach to the problem, one of them being, a close taxonomic study of the Peninsular species showing Malayan affinities, and an analysis of their different levels of evolutionary divergences. In this article, the taxonomic status of certain forms like *Rohtee* Sykes, *Puntius ticto* Ham., *Osteobrama* Heckel, *Silonia* Swainson, *Silurus* Linnaeus, *Clarias* Gronovius, and *Pristolepis* Jerdon, which needed further clarification, is elucidated. A complete list of the important Peninsular Isolates with their eastern affinities is given. Migration of torrential fishes from the region of the Eastern Himalayas across the Garo-Rajmahal Gap was possible during the 'Pluvial Periods' of the Pleistocene, which coincided with the Glacial epochs of the north. During these cold phases there was a general drop in the sea-level, but subsequent rise in sea-level during the 'Arid Periods' (which would have corresponded with the Interglacials) temporarily checked migration and thus isolated certain forms. The continuous Narbada-Tapti River of the early Pleistocene would have also considerably helped in the dispersal of forms to the Peninsula from the east.

The scrap faulting of the West Coast and the tilting of the Peninsula during the Pleistocene reversed the drainage system and also rejuvenated the streams and rivers. This, in addition to the climatic fluctuations gave sufficient impetus for rapid speciation among the Peninsular Isolates. The 'Pre-tilt forms' diverged most, while the 'Post-tilt forms' have only slightly diverged from the parent stock. Endemicity and the degree of divergence is most pronounced in the extreme southern section of the Western Ghats. A gradual decrease is seen as one goes up along the Ghats and then the Vindhya Satpura trend of mountains. High endemicity is a clear proof of the longer isolation of the forms of the Peninsula. The divergence is greatest in the species found in the hill-streams which in turn were rejuvenated by the physiographic changes of the Peninsula during the Pleistocene. The probable sequence of migration of these forms are also dealt with in the last section.

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GENERAL LENGTH-WEIGHT RELATIONSHIP OF THREE MAJOR CARPS OF INDIA.[1]

By V. G. JHINGRAN, *Central Inland Fisheries Research Station, Barrackpore, India.*

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INTRODUCTION.

This paper deals with the study of the relationship between the furcal length [2] and weight of the Indian Cyprinids *Catla catla* (Ham.), *Cirrhina mrigala* (Ham.) and *Labeo rohita* (Ham.). The main object here has been to derive appropriate mathematical formulae, correlating the two variables length and weight, in a very general manner, for calculating one from the other within a certain range of error. The related issue of 'condition' of fish has not been touched in this study. In view of the object of this paper, mentioned above, an extensive size range, for each species, has been included in this study; collections from different localities were taken; the sex factor was not reckoned as also the gonadial condition and gut contents. The material is, therefore, heterogeneous. It is recognised that a single general value of n in the general length-weight equation: $W = cL^n$ (see 'Historical') not only does not apply for all lengths of fish with uniform accuracy, but fluctuates from habitat to habitat. The former general fact which has been elucidated by Clark (1928), Walford (1932) and Schultz (1933) for other species has also been indicated in the present study. In the present work, however, only single general values of c and n have been derived. The fluctuations of these factors will be worked out in a separate paper as soon as additional data from varying habitats are compiled.

HISTORICAL.

Ever since Herbert Spencer first enunciated the 'cube law' in 1871 its application to fish measurements has been carried out by numerous workers.

[1] Published with the kind permission of the Chief Research Officer, Central Inland Fisheries Research Station, Barrackpore.

[2] The expression furcal length denotes the length of the fish between the anterior extremity of the snout and the point where the caudal fin bifurcates. This has been chosen in place of total length or standard length because the former is often vitiated by wear and tear and the latter though very reliable and accurate is difficult to ascertain by external examination.

According to this law the weight of a fish equals the cube of the length times a constant. Symbolically it is expressed as: $W = aL^3$, where W = Weight, L = length and a = constant. This relationship assumes a constancy of form and specific gravity on the part of the fish. Reibisch (1908) found no appreciable seasonal variation in the specific gravity of the plaice. Keys (1928) stated that there can be little change in the specific gravity of the fish so long as it remains in the same environment. During the earlier investigations on the applicability of the 'cube law' to fish, beginning with Hensen in 1899, the constant a was found to fluctuate and Heincke, in 1908, proposed the use of this factor as an index of the well-being of fish. This factor has been variously termed as coefficient of condition, condition, length-weight factor, etc. Crozier and Hecht (1913) and Hecht (1916) found the cube law applicable to the fishes they investigated, but these instances appear to be exceptions rather than the rule. Fulton, in 1904, showed the inadequacy of the 'cube law' in describing the length-weight relationship of fishes. In recent years a much more satisfactory way of describing the length-weight relationship of fishes has been developed through the use of a more general equation: $W = cL^n$, where W = Weight, L = Length and c and n = constants. The values of c and the exponent n are determinable empirically. Such a relationship has been worked by a host of workers on different fishes who, among others, include Järvi (1920), Tjurin (1927), Clark (1928), Keys (1928), Fraser (1931), Hart (1931 and 1932), Tester (1932), Walford (1932), Shultz (1933), Hile (1936 and 1941), Hile and Jobes (1940 and 1941), Foerster (1936), Van Oosten (1942), Beckman (1942 and 1945), Deason and Hile (1944), and Jobes (1946 and 1947). Most of the above stated authors, besides determining the length-weight relationship of the fish they investigated, have also determined the condition factor of the fish. A great deal of confusion appears to have arisen in describing the condition of a fish and the expression of the length-weight relationship. Hile (1936, page 240) has thrown light by elaborating upon the theme 'coefficients based on empirical exponents fail to reflect differences in form or relative heaviness while those based on cube relationship offer a direct measure of relative heaviness independent of general length-weight relationship and comparable as measures of relative heaviness between fish of any length'.

In India very little work has been done on the length-weight relationship of different species of fish and this is mainly on Mahseer *Barbus* (Tor) *putitora* (Ham.) for which Lacey and Cretin (1905) and Treven (1925) have advanced some formulae. The formula mentioned by Lacey and Cretin is:

$$\frac{\text{Length and one-third length} \times \text{girth squared in inches}}{1{,}000} = \text{Weight.}$$

According to the latter authority 1¼ length of the fish multiplied by the square of the girth in inches and divided by 1,000 gives the weight of the fish in pounds. Hamid Khan and Hussain (1945) studied the length-weight relationship of *Labeo rohita* and *Cirrhina mrigala* from the departmental fish farm at Chhenawan, Punjab, India. His conclusions are that the weight (in chhataks)[1] of these fish can be known at a certain length (in cm.) by multiplying the cube of the length with the weight-length factor, which are:

(1) *Labeo rohita*	·000238
(2) *Cirrhina mrigala* ..	·000180

Material and Methods.

The specimens studied include those from natural unfertilised waters like rivers and canals and from untreated tanks and ponds. Specimens of *Catla catla*

[1] A chhatak = about 2 oz.

smaller than 129·5 mm., of *Cirrhina mrigala* smaller than 133 mm. and of *Labeo rohita* smaller than 176 mm., each in furcal length, for this study, were secured from the Moat at Cuttack, in Autumn and Winter of 1949 and in Spring of 1950. Those of *Catla catla* larger than 129·5 mm., of *Cirrhina mrigala* larger than 133 mm. and of *Labeo rohita* larger than 176 mm. were mostly got from Tank No. 3 at Jobra, Cuttack in Winter, 1949. Some of the specimens of *Cirrhina mrigala* and *Labeo rohita* larger than 133 and 176 millimetres respectively were secured in part from one of the Pulta Water Works settling tanks and in part from other sources like the Ganges at Dhulian Ganges in Murshidabad District, West Bengal. No specimen of *Catla catla* came from either of the latter sources.

The Moat at Cuttack is a canal encircling the old fort, about 3/4ths of a mile long and about 50 feet wide. It is fed by the river Mahanadi. It was stocked with major carp fry for the first time in summer, 1949. Prior to then it was an unutilised piece of water. Tank number 3 at Jobra, Cuttack, is one of the nine tanks existing there for a long time and contained fish stocked from a variety of sources during the past three or four years.

The measurements of the fish given in this paper were made on the usual fish-measuring board, divided into millimetres. The fish captured from the Moat, Cuttack, were preserved in 5% formalin in the field. They were subsequently dried for half a minute in the folds of a blotting paper, and then measured and weighed on a platform balance to the nearest 1/10th of a gram. Fish longer than 160 mm. in furcal length were weighed fresh either with a spring balance or on a platform balance. No allowance for shrinkage was made in the case of fish preserved in formalin. The calculated values of weights were rounded at the first decimal place.

Correlation tables were used throughout this study for the calculation of various factors necessary for the expression of length-weight relationship. Length was used as the type and weight as the array. The equation adopted in all the three cases was that of the general parabola: $W = cL^n$, explained under the heading entitled 'Historical' in this paper. This equation when expressed in logarithmic form becomes: Log W = Log $c + n$ Log L, which when graphically represented assumes a linear form. The values of c and n were determined empirically. In the absence of a calculating machine coding had to be resorted to. The following formulae (Simpson & Roe, 1939) were used to determine the exponents:

1. $\log C = M_y - (n)\, M_x$ where M_y = mean of y and M_x mean of x, and

2. $n = r \frac{\sigma_y}{\sigma_x}$ where r = coefficient of correlation,

σ_y = standard deviation of y, and
σ_x = standard deviation of x

$$r = \frac{\Sigma(dA_x . dA_y)}{N(\sigma_x . \sigma_y)} - Cl_x . Cl_y .$$

$$\sigma_x \text{ (or } \sigma_y) = i \frac{\sqrt{\Sigma(fd^2A)}}{N} - C_1^2$$

where i = the class interval
dA = deviation of assumed mean in terms of class interval and
Cl = difference between mean and assumed mean in terms of class interval.

The details of calculations are not given, being of a routine nature and well known.

Length-weight relationship of *Catla catla* (Ham.).

The data on *Catla catla* consisted of measurements of 172 specimens ranging in furcal length from 41 mm. to 405 mm. and in weight from 1·5 gm. to 1,672·625 gm. The formula correlating length and weight of this species is given below:

$$\text{Weight} = 0{\cdot}8917 \times 10^{-5} \times \text{Length}^{3{\cdot}15172}$$

The logarithmic form of the above equation is:

$$\text{Log Weight} = -5{\cdot}04976177242 + 3{\cdot}15172 \text{ Log Length}$$

The coefficient of correlation between the log length and log weight is 0·988. The standard error of estimate in terms of logs is ±0·09415. Figure 1 presents the directly observed length and weight values on an ordinary arithmetic grid. The curve shown in this figure corresponds to the equation specific for *Catla catla* given above.

Length-weight relationship of *Cirrhina mrigala* (Ham.).

The data on *Cirrhina mrigala* consisted of measurements of 347 specimens ranging in furcal length from 46 mm. to 790 mm. and in weight from 1·2 gm. to 7,427·576 gm. The formula correlating length and weight of this species has been found to be:

$$\text{Weight} = 1{\cdot}196 \times 10^{-5} \times \text{Length}^{3{\cdot}0248352}$$

The logarithmic form of the above equation is:

$$\text{Log Weight} = -4{\cdot}922212022 + 3{\cdot}0248352 \text{ Log Length}$$

The coefficient of correlation between the log length and log weight is 0·992 and the standard error of estimate in terms of logs is ±0·0754. Figures 2 and 3 show the observed length and weight values. The curves drawn in these figures are in accordance to the formula given above.

Length-weight relationship of *Labeo rohita* (Ham.).

The data on *L. rohita* consisted of observations on 275 specimens varying in furcal length from 50 mm. to 620 mm. and in weight from 2·0 gm. to 4,989·6 gm. The formula correlating length and weight of this species was determined to be:

$$\text{Weight} = 1{\cdot}554 \times 10^{-5} \times \text{Length}^{3{\cdot}0140028}$$

The logarithmic form of the above equation is:

$$\text{Log Weight} = -4{\cdot}80836464485 + 3{\cdot}0140028 \text{ Log Length}$$

The coefficient of correlation between log length and log weight is 0·994 and the standard error of estimate in terms of logs is ±0·0739. Figure 4 shows a plot of observed weights against the observed length values. The curve drawn in this figure is in accordance with the equation derived for *Labeo rohita*.

General Remarks.

The reliability of the equations derived in this paper would be seen to be high from the coefficient of correlation values in all the three cases.

It is seen in Figure 1 that the weight values of *Catla catla* corresponding to the length values ranging from 80 mm. to 120 mm. have a tendency to group below the line of calculated weights. The reverse tendency for weight values to exceed those calculated is discernible at the size range, 120 mm. to 150 mm., as is seen in Figure 1. The trend for observed weight values to concentrate above the line in the case

of *Cirrhina mrigala* is seen opposite the furcal length range, 60 mm. to 97 mm., in Figure 2. The trend in the opposite direction in the case of this species is seen clearly against the length range 115 mm. to 138 mm. In the case of *Labeo rohita* there appears to be a poor agreement between recorded weights for fish larger than 490 mm. as is seen in Figure 4, the observed weight values generally exceeding the calculated ones. All these observations appear to indicate that single values of c and n do not hold for the entire size range of fish. Similar trends have been pointed out in the case of the California *Sardine caerulea*, by Clark (1928). Walford (1932) and Schultz (1933) have also indicated similar trends in the cases of California Barracuda, *Sphraena argentia* and *Athrinops affinis oregonia* respectively. In order to elucidate this point in the cases of fishes reported upon in the present paper a greater mass of data is required for those size ranges where the calculated weights do not hold in a general manner. These points will be dealt with as soon as more data is available.

It is evident from the values of the exponents n in the general length-weight equation: $W = Cl^n$, that *Catla catla* departs most from the 'cube law'. Next in the sequence is *Cirrhina mrigala* and finally comes *Labeo rohita*, which departs least from the 'cube law'.

For the sake of comparison of relative weights of the three major carps studied, weights of the three species for 100, 200, 300, 400 and 500 millimetres furcal lengths have been calculated and are presented in Table I. Figure 5 gives the graphic representation of the same data for all the three species of Indian carps.

TABLE I.

Weights of the three major carps of a few selected lengths.

Furcal Length in mm.	Weight in grams.		
	Catla catla.	*Labeo rohita.*	*Cirrhina mrigala.*
100 ..	17·9	16·6	13·4
200 ..	159·4	134·0	109·2
300 ..	572·0	454·6	371·9
400 ..	1,417·0	1,081·0	889·2
500 ..	2,863·0	2,119·0	1,745·0

The comparative increase in weight as compared to length is, therefore, most in *Catla catla*, next in *Labeo rohita* and least in *Cirrhina mrigala*. It may be recorded that Hamid Khan and Hussain (1945) also found that length for length *Labeo rohita* is heavier than *Cirrhina mrigala*. This paper, therefore, confirms Hamid Khan's observations in this respect. These authors, however, did not empirically determine the value of n in the general length-weight equation and stated that the weights of *Labeo rohita* and *Cirrhina mrigala* tend to increase approximately to the cube of the length. This paper gives the exact values of the exponents of L in the three species of major carps studied in the general formula: $W = cL^n$. The 'cube law' is clearly an obsolete conception in describing the length-weight relationship of fishes. Hamid Khan used total length as the measure of fish length. In the present study, however, furcal lengths were used and hence the results are not comparable. It is necessary to work out conversion factors between the different fish lengths commonly used in fisheries work before the data gathered on different length measures can be mutually compared.

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Summary.

1. Analysis of 172 specimens of *Catla catla*, ranging in furcal length from 41 mm. to 405 mm. shows that the formula, correlating length with weight, specific for this fish within this size range is:

Weight $= 0{\cdot}8917 \times 10^{-5} \times \text{Length}^{3{\cdot}15172}$ which in logarithmic form is:

Log Weight $= -5{\cdot}04976177242 + 3{\cdot}15172$ Log Length.

The standard error of estimate in terms of logs is $\pm 0{\cdot}09425$.

2. Analysis of 317 specimens of *Cirrhina mrigala*, ranging in furcal length from 46 mm. to 790 mm. shows that the formula, correlating length with weight, specific for this fish within this size range is:

Weight $= 1{\cdot}196 \times 10^{-5} \times \text{Length}^{3{\cdot}0248352}$ which in logarithmic form is:

Log Weight $= -4{\cdot}922212022 + 3{\cdot}0248352$ Log Length.

The standard error of estimate in terms of logs is $\pm 0{\cdot}0754$.

3. Analysis of 275 specimens of *Labeo rohita*, ranging in furcal length from 50 mm. to 620 mm. shows that the formula, correlating length with weight, specific for this fish within this size range is:

Weight $= 1{\cdot}554 \times 10^{-5} \times \text{Length}^{3{\cdot}0140928}$, which in logarithmic form is:

Log Weight $= -4{\cdot}80836464485 + 3{\cdot}0149928$ Log Length.

The standard error of estimate in terms of logs is $\pm 0{\cdot}0739$.

4. The coefficients of correlation between log length and log weight of *Catla catla*, *Cirrhina mrigala* and *Labeo rohita* are: 0·988, 0·992 and 0·994 respectively. The high values of correlation coefficient shows that the reliability of the equations derived in this report is high.

5. Single values of c and n in the general length-weight equation, Weight $= c$ Length^n do not appear to hold good for the entire length range of fish with uniform accuracy.

6. *Catla catla* departs most from the 'cube law'. *Cirrhina mrigala* comes next and *Labeo rohita* stands last in this respect, deviating least from the 'cube law'.

7. In the order of heaviness *Catla catla* comes first, next is *Labeo rohita* and last is *Cirrhina mrigala*.

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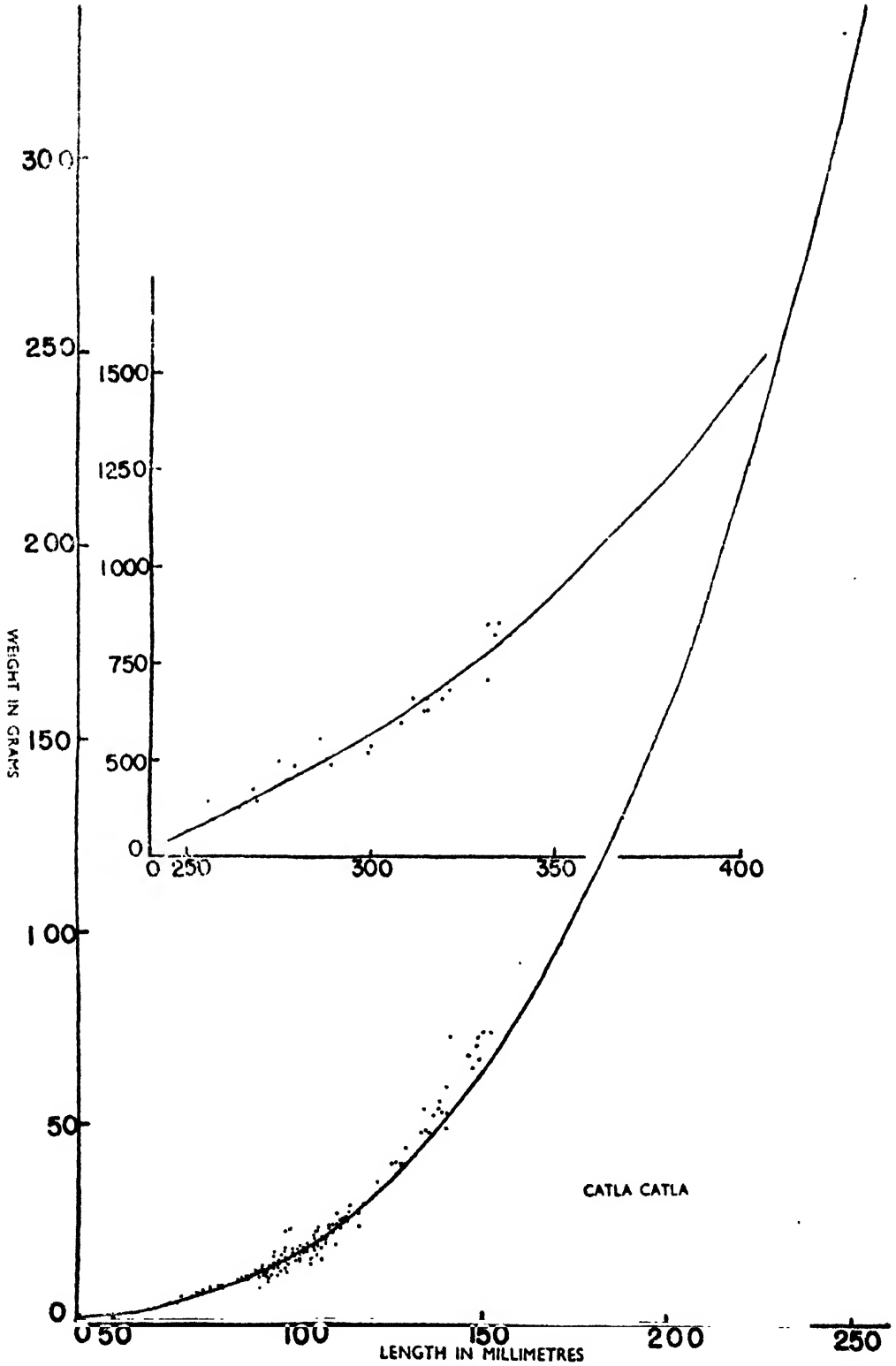
300
250
200
150
100
50
0
WEIGHT IN GRAMS
0 50 100 150 200 250
LENGTH IN MILLIMETRES
1500
1250
1000
750
500
0
0 250 300 350 400
CATLA CATLA

FIGURE 1

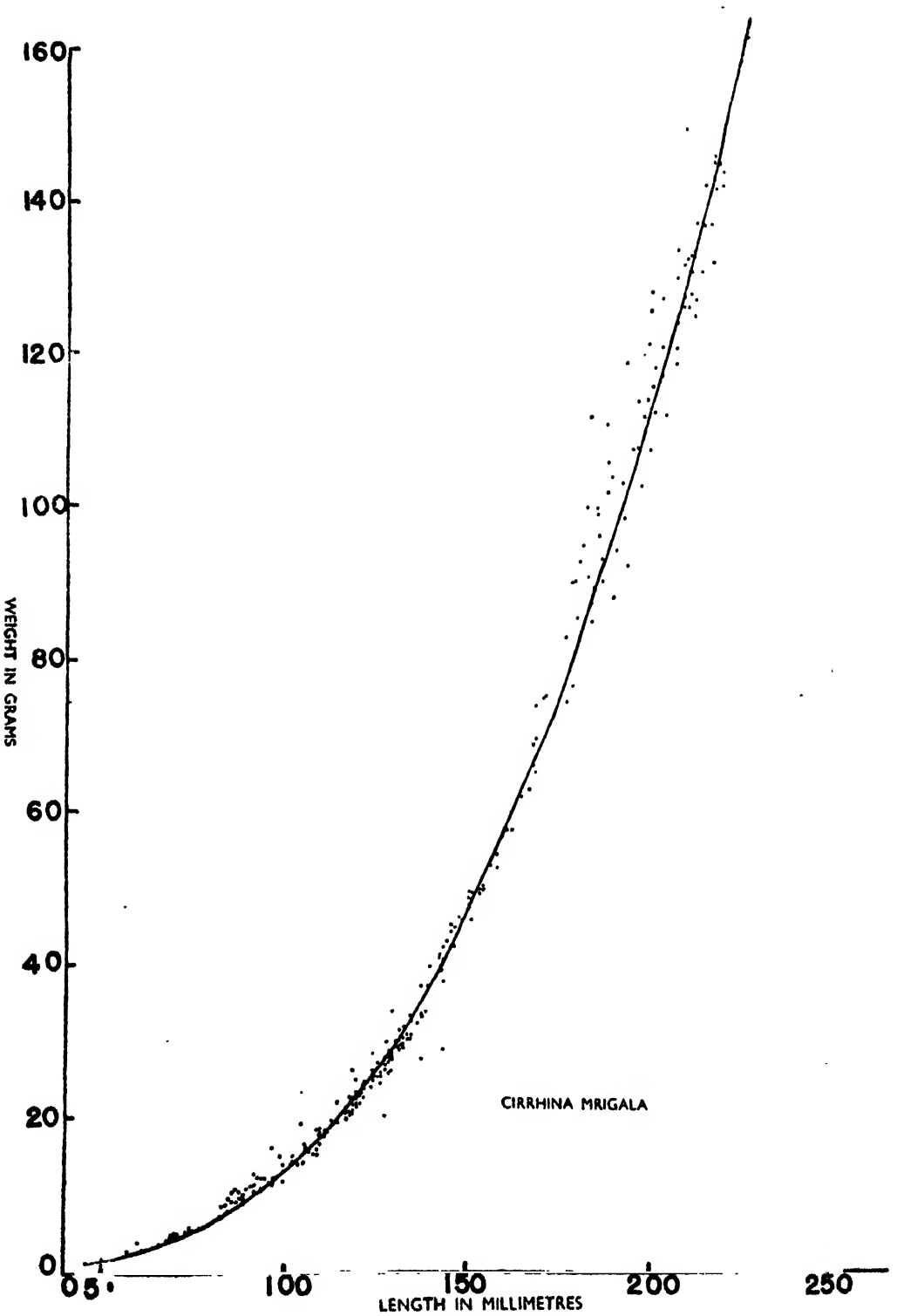
160
140
120
100
80
60
40
20
0
WEIGHT IN GRAMS
CIRRHINA MRIGALA
05
100
150
200
250
LENGTH IN MILLIMETRES

FIGURE 2

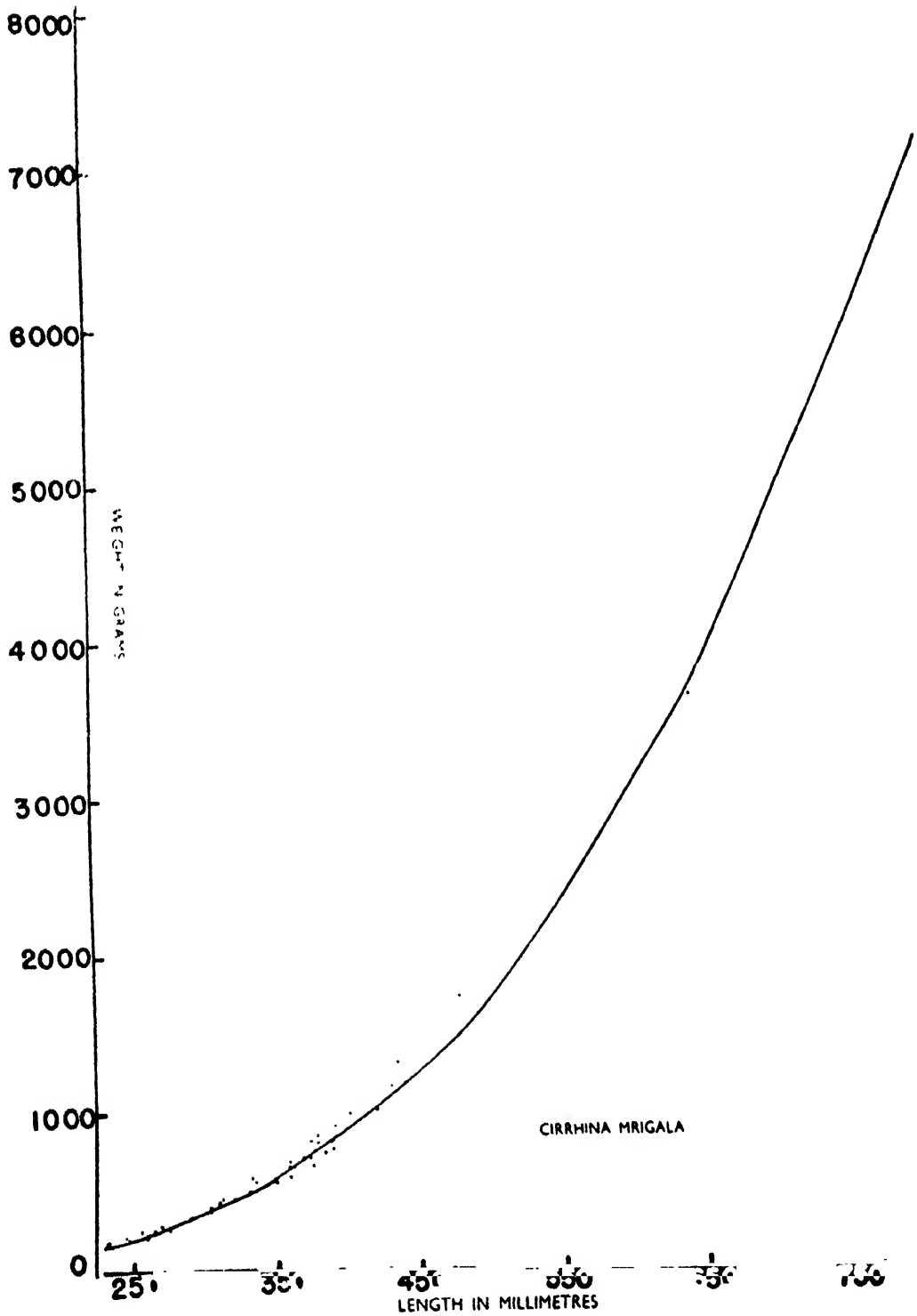
8000
7000
6000
5000
4000
3000
2000
1000
0
WEIGHT IN GRAMS
CIRRHINA MRIGALA
25
35
45
55
65
LENGTH IN MILLIMETRES

FIGURE 3

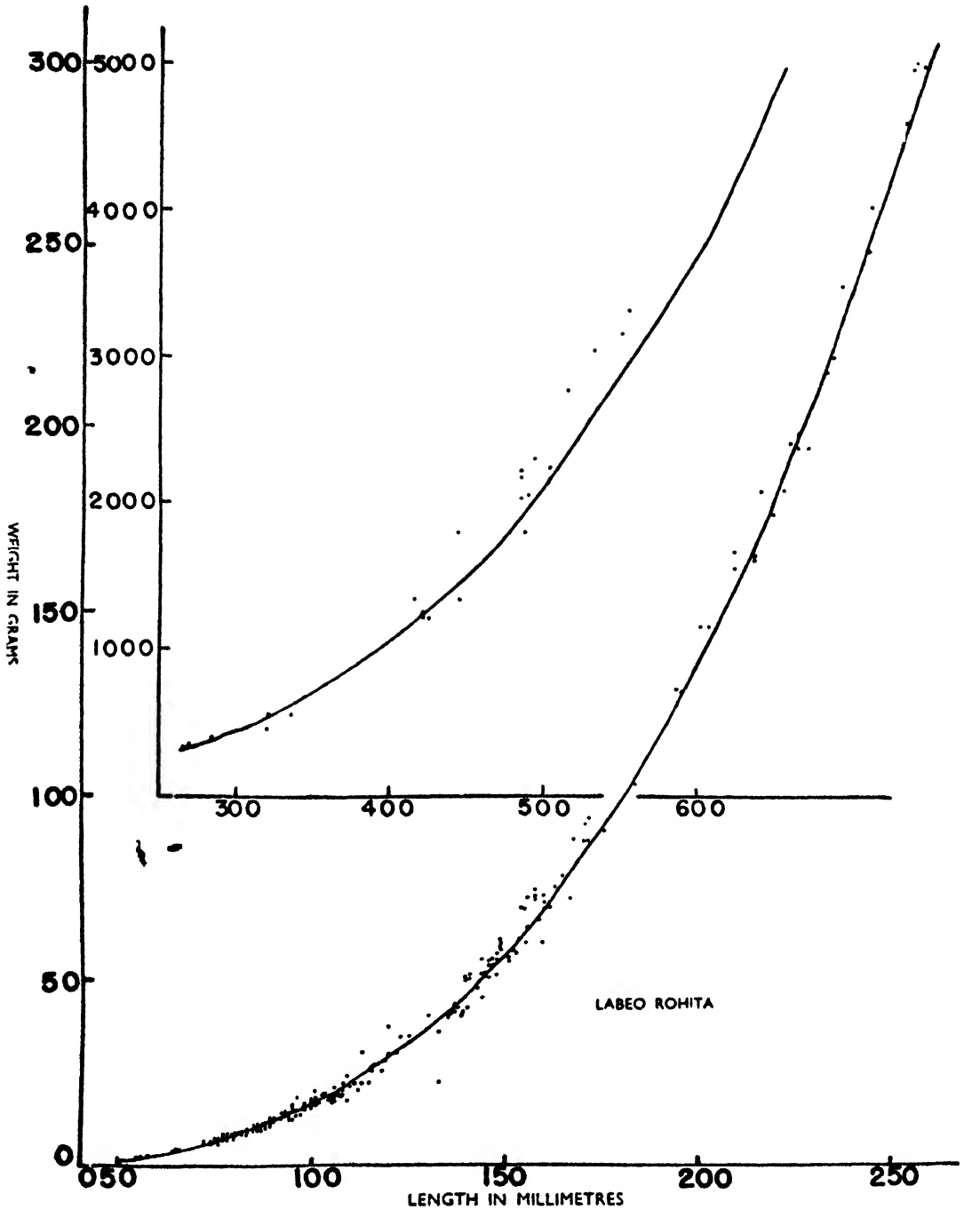
300
250
200
150
100
50
0
5000
4000
3000
2000
1000
WEIGHT IN GRAMS
300
400
500
600
LABEO ROHITA
050
100
150
200
250
LENGTH IN MILLIMETRES

FIGURE 4

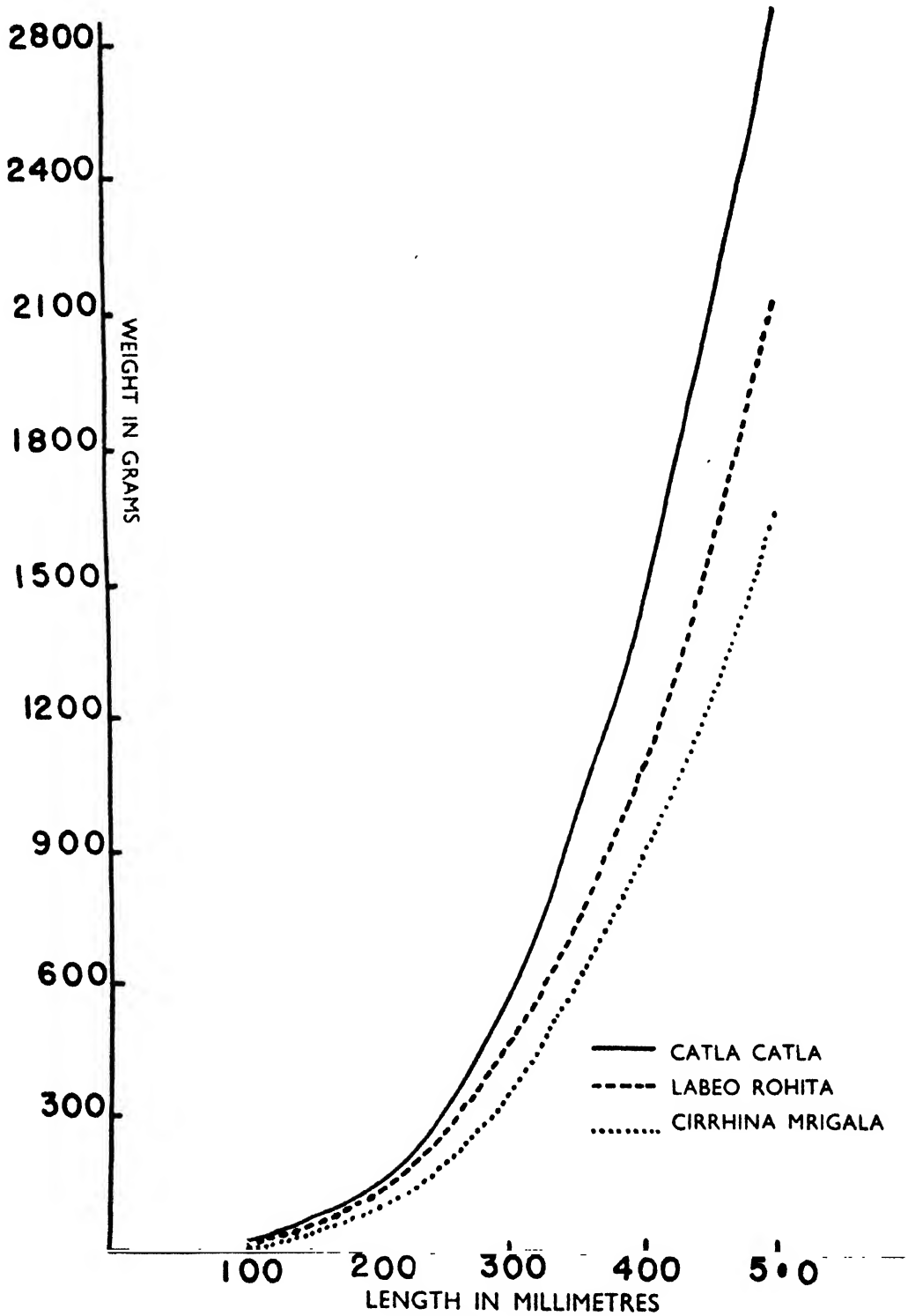
2800
2400
2100
1800
1500
1200
900
600
300
WEIGHT IN GRAMS
100
200
300
400
500
LENGTH IN MILLIMETRES
CATLA CATLA
LABEO ROHITA
CIRRHINA MRIGALA

FIGURE 5

ADIABATIC PULSATIONS OF A PARTICULAR MODEL OF THE VARIABLE STAR.

By R. S. KUSHWAHA, *Department of Mathematics, University of Allahabad.*

(Communicated by Prof. A. C. Banerji, F.N.I.)

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INTRODUCTION.

Eddington, Edgar (1933), Schwartzschild (1941) and others have considered the modes of small radial adiabatic oscillations of the standard model (Polytrope of index 3). Eddington's results show a period of oscillation which is short of the observed value by a factor near about 2. This fact points to the lower central concentration in actual Cepheids than the one given by the standard polytrope.

After this people tried different laws of variation of density. Dr. Sterne (1937) considered the small radial adiabatic oscillations for the following three models:

(1) The homogeneous density distribution throughout the star.
(2) A model in which the density varies inversely as the square of the distance from the centre of the star.
(3) A model with nearly all the mass concentrated at the centre and in the rest of the star the density varies inversely as the square of the distance from the centre.

Very recently Professor A. C. Banerji (1942) has given an entirely new and very interesting theory of the origin of solar system based on the instability of large radial oscillations of the following two models:

(1) The star with homogeneous density distribution.
(2) The star with small homogeneous core and the density in the envelope varying inversely as the p-th power of the distance from the centre, where p is any positive integer excluding 1 and 3.

This work of Prof. Banerji is very important as it throws an important light on the density concentration in the Cepheid variables. Dr. H. K. Sen (1942) also considered the stability of radial oscillations of similar models.

In the models where density varies inversely as some power of the distance from the centre we have singularity at the centre. To avoid this Prof. Banerji took a small central core. Another way to do it was to take the law for variation of density as $\rho_0 = \rho_c\left(1-\frac{r_0^n}{R^n}\right)$, where the notations have their usual meaning. Analytically the approximate solutions of the pulsation equation could be obtained (1949) only for $n = 2$, for which the model was found to be stable.

Knowing that the model is stable for homogeneous density distribution and also for the law $\rho_0 = \rho_c\left(1-\frac{r_0^2}{R^2}\right)$, it can very well be expected that for the law $\rho_0 = \rho_c\left(1-\frac{r_0}{R}\right)$, the model must be stable. The author has considered this model and found correct to our expectation.

Equations of the problem.—The differential equation for small adiabatic radial oscillations of a star as obtained by Eddington is

$$\frac{d^2\xi}{dr_0^2}+\frac{4-\mu}{r_0}\frac{d\xi}{dr_0}+\left\{\frac{\rho_0\sigma^2}{\gamma P_0}-\frac{\alpha\mu}{r_0^2}\right\}\xi=0, \quad .. \quad .. \quad .. \quad (1)$$

where

$$\frac{\delta r}{r_0}=\xi(r_0)\,e^{i\sigma t}, \quad .. \quad .. \quad .. \quad .. \quad (2)$$

$$\alpha=3-\frac{4}{\gamma}, \quad .. \quad .. \quad .. \quad .. \quad .. \quad (3)$$

$$\mu=\frac{g_0\rho_0 r_0}{P_0}, \quad .. \quad .. \quad .. \quad .. \quad .. \quad (4)$$

and r_0, ρ_0, P_0, g_0, are the equilibrium values of the distance from the centre, density, pressure and gravity at a point. Here the boundary conditions are

$$\delta P=-\gamma P_0\left(3\xi+r_0\frac{d\xi}{dr_0}\right)=0 \text{ at } r_0=R, \quad .. \quad .. \quad (5)$$

and ξ is finite everywhere in the region $0<r<R$

For this model putting $x=\frac{r_0}{R}$ we have

$$\rho_0=\rho_c(1-x), \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (6)$$

$$g_0=4\pi G\rho_c Rx\left(\frac{1}{3}-\frac{x}{4}\right), \quad .. \quad .. \quad .. \quad .. \quad .. \quad (7)$$

$$P_0=4\pi G\rho_c^2R^2\left(\frac{5}{144}-\frac{x^2}{6}+\frac{7x^3}{36}-\frac{x^4}{16}\right). \quad .. \quad .. \quad .. \quad (8)$$

Substituting these values in (1) we get

$$x(1-x)(5+10x-9x^2)\frac{d^2\xi}{dx^2}+(20+20x-124x^2+72x^3)\frac{d\xi}{dx}$$
$$+\{f-12\alpha(4-3x)\}x\xi=0, \quad .. \quad .. \quad (9)$$

where

$$f=\frac{36\sigma^2}{G\pi\gamma\rho_c}. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (10)$$

The equation (9) has singularities at $x=0$ and $x=1$. We have to find the solution which is finite in the region $0<x<1$.

If we substitute the series

$$\xi=x^m\sum_{n=0}^{\infty}a_n x^n, \quad .. \quad .. \quad .. \quad .. \quad (11)$$

in (9) we find that the roots of the indicial equation are zero and -3. To satisfy the physical conditions of the problem we have to choose the former one. The recurrence formula for the coefficients of the series is

$$(9n^2+27n-90+36\alpha)a_{n-2}-(19n^2+67n-86-f+48\alpha)a_{n-1}$$
$$+(5n^2+15n)a_n+5(n^2+5n+4)a_{n+1}=0. \quad .. \quad (12)$$

If the $\lim_{n\to\infty} \frac{a_{n+1}}{a_n} = l$

we find that this limit l will be the root of the equation

$$9-19l+5l^2+5l^3=0 \quad .. \quad .. \quad .. \quad .. \quad (13)$$

Obviously its roots are 1, 0·7 and −2·7. For $l = 1$ and −2·7 the series will be divergent. Only for $l = 0{\cdot}7$ it will be convergent. But the difficulty here comes in is how to get that value of f for which the limit is 0·7. This difficulty is overcome by Rayleigh-Ritz method (1941) for finding the approximate period for any oscillatory stellar model. After getting the approximate value of f, the pulsation equation has been integrated numerically to see actually if the amplitude remains finite throughout the star and also at the surface.

Process of integration:

Putting

$$\xi = \Psi e^{-\frac{1}{2}\int \frac{72x^3-124x^2+20x+20}{x(1-x)(5+10x-9x^2)}dx}, \quad .. \quad .. \quad .. \quad (14)$$

the differential equation reduces to

$$\frac{d^2\Psi}{dx^2}+I\Psi=0, \quad .. \quad .. \quad .. \quad .. \quad (15)$$

where

$$I=\frac{f-48\alpha+36\alpha x}{(1-x)(5+10x-9x^2)}-\frac{50+150x-780x^2-920x^3+2376x^4-972x^5}{x^2(1-x)(5+10x-9x^2)^2}. \quad (16)$$

Equation (14) gives

$$\Psi = \xi x^2(1-x)\sqrt{5+10x-9x^2}. \quad .. \quad .. \quad .. \quad (17)$$

Put (15) in the form

$$\frac{d^2\Psi}{dx^2} = F(x), \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (18)$$

where

$$F(x) = \xi x^2(1-x)\sqrt{5+10x-9x^2}\left\{\frac{50+150x-780x^2-920x^3+2376x^4-972x^5}{x^2(1-x)(5+10x-9x^2)^2}\right.$$
$$\left.-\frac{f-48\alpha+36\alpha x}{(1-x)(5+10x-9x^2)}\right\}. \quad .. \quad (19)$$

To solve the equation (18) we apply Adam's method of integration as sketched by Von Zeipel in one of his papers (1924). Here the equidistant intervals were taken for x at a distance 0·02 ($\omega = 0{\cdot}02$). The difference formula

$$\Psi''(n\omega) = \omega^2 F(n\omega)+\frac{\omega^2}{12}F''(n\omega)-\frac{\omega^2}{240}F^{iv}(n\omega), \quad .. \quad .. \quad (20)$$

helps us to integrate the equation (18) leading successively to the knowledge of the values of $\Psi(x)$ for $x = (n+1)\omega$, $(n+2)\omega$, $(n+3)\omega$, $(n+4)\omega$, .. etc.

Here ω being very small we neglected the difference $F^{iv}(n\omega)$ and by the process of extrapolation an approximate value of $\frac{\omega^2}{12}F''(n\omega)$ was obtained. By method of checking a more accurate value of $\frac{\omega^2}{12}F''(n\omega)$ was found. Hence the value of $\Psi(n\omega)$ was calculated with the knowledge of $\Psi(\overline{n-1}\omega)$ determined previously. Consequently the values of the amplitude were also calculated. These values are given in the table as ξ and Ψ for two values of f ($f = 13{\cdot}2$ and $f = 13{\cdot}3$).

TABLE.

$x = \frac{r_0}{R}$	For $f = 13{\cdot}2$		For $f = 13{\cdot}3$	
	$\Psi = \frac{}{\xi x^2(1-x)\sqrt{5+10x-9x^2}}$	ξ/a_0	$\Psi = \frac{}{\xi x^2(1-x)\sqrt{5+10x-9x^2}}$	ξ/a_0
0·000	0·0	1	0·0	1
0·02	0·000 8936966	1·00012164	0·0008936959	1·00012085
0·04	0·003566278	1·000474985	0·003566262	1·00047184
0·06	0·00799314	1·00104482	0·007993087	1·0010378
0·08	0·01413525	1·00181845	0·01413507	1·001806
0·10	0·02194038	1·0027855	0·02193996	1·002766
0·12	0·03134454	1·0039435	0·03134367	1·00391524
0·14	0·04227641	1·00536267	0·042274803	1·005324083
0·16	0·0546862	1·0076337	0·05468351	1·0075834
0·18	0·06844554	1·0098323	0·068441167	1·0097676
0·20	0·08344842	1·012(081	0·0834418	1·01192796
0·22	0·099584507	1·014231	0·09957493	1·014134
0·24	0·11673625	1·016309	0·11672286	1·01619
0·26	0·13477926	1·018959	0·13476106	1·018822
0·28	0·15358292	1·021495	0·153568799	1·0214015
0·30	0·17301099	1·024162	0·17299967	1·024095
0·32	0·19292197	1·026963	0·19291206	1·0269106
0·34	0·2131696	1·029899	0·2131595	1·029857
0·36	0·23360324	1·03298	0·2335912	1·032933
0·38	0·254068324	1·036214	0·25405238	1·036149
0·40	0·27440668	1·0395909	0·27438465	1·039507
0·42	0·29445696	1·043123	0·29442643	1·043012
0·44	0·31405495	1·046805	0·31401324	1·046667
0·46	0·333033973	1·050649	0·33297824	1·050474
0·48	0·35122524	1·054657	0·35115241	1·054438
0·50	0·368458186	1·0588335	0·36836494	1·0585656
0·52	0·38456077	1·0631809	0·38444364	1·062857
0·54	0·399360005	1·0677077	0·3992152	1·0673206
0·56	0·4126821	1·072418	0·4125058	1·071959
0·58	0·42435300	1·0773194	0·42414102	1·0767813

(TABLE—Continued).

$x = \frac{r_0}{R}$	For $f = 13{\cdot}2$		For $f = 13{\cdot}3$	
	$\Psi = \xi x^2(1-x)\sqrt{5+10x-9x^3}$	ξ/a_0	$\Psi = \xi x^2(1-x)\sqrt{5+10x-9x^3}$	ξ/a_0
0·000	0·0	1	0·0	1
0·60	0·4341987	1·082417	0·4339468	1·081789
0·62	0·4420456	1·087722	0·4417493	1·086993
0·64	0·44772097	1·093242	0·4473757	1·092399
0·66	0·45105334	1·098983	0·450655	1·097972
0·68	0·451873007	1·104961	0·45141595	1·103843
0·70	0·45001242	1·1111829	0·449492	1·109899
0·72	0·4453067	1·117666	0·44471923	1·116191
0·74	0·43759433	1·124418	0·43693485	1·122724
0·76	0·4267174	1·131459	0·4259817	1·129508
0·78	0·41252254	1·138806	0·4117053	1·13654
0·80	0·3948615	1·146482	0·39395914	1·143862
0·82	0·3735917	1·154496	0·3726033	1·151441
0·84	0·34857742	1·1628887	0·34750046	1·1592959
0·86	0·319690388	1·171689	0·31852458	1·167416
0·88	0·2868117	1·18094	0·28555855	1·17578
0·90	0·24983002	1·190689	0·24849362	1·18432
0·92	0·20864555	1·201022	0·2072337	1·192896
0·94	0·163170492	1·212093	0·161696887	1·201147
0·96	0·113330443	1·22432	0·111818356	1·207999
0·98	0·059064002	1·239302	0·05755772	1·207697
1·00	0·0003196	$+\infty$	−0·0010773	$-\infty$

CONCLUSION.

The value of ξ from the value $\Psi(x)$ is calculated by the equation (17) from which it is clear that at $x = 1$, Ψ must tend to zero. But due to rough approximations it is impossible to get actually the value zero. Hence we see that for $f = 13{\cdot}2$, Ψ is positive at the surface giving $\xi = +\infty$ there, and for $f = 13{\cdot}3$ we get $\Psi(x)$ negative making $\xi = -\infty$. Hence we can quite safely conclude that the value of f which will make $\Psi = 0$ and consequently give a finite value for the displacement at the surface, must lie between these above two values. We therefore conclude that for the fundamental mode the value of f satisfying the equation (9) and keeping ξ finite

at the surface is positive. Thus the radial oscillations for our model are proved to be stable. As we know that it is always the fundamental mode which becomes unstable first we can say in the present case that all the higher modes will also be stable. So we see here that the results obtained do not betray our expectation that a stellar model which lies between two stable models must also be stable.

The author considers it a great privilege to record his most respectful thanks to Prof. A. C. Banerji, under whose guidance he has carried out the above investigation.

Summary.

The stability of a model in which the density varies in the interior of a star according to the law $\rho_0 = \rho_c\left(1-\frac{r_0}{R}\right)$, where ρ_0 is the density at any point, ρ_c the density at the centre, r_0 the equilibrium value of the distance of the point from the centre and R the radius of the star, has been studied in this paper. It is found to be stable, and the period of oscillation and the amplitude of displacement at the different points inside the star are obtained by numerical integration.

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A NOTE ON THE TRANSITION FROM VISCOUS TO PERFECT FLUID FLOW

By Dr. N. L. Ghosh, *Research Fellow, N.I.S.I., Department of Applied Mathematics, Calcutta University.*

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Introduction.

Elegant solutions of the potential motion of a perfect fluid past a solid obstacle have long been known. It is also well-known that the Navier-Stokes equations of motion of a viscous fluid reduce to the Eulerian equations of motion of a perfect fluid in the limit when μ, the coefficient of viscosity, tends to zero. One might therefore ask if a viscous shear flow ($\mu \neq 0$) can reduce to a potential flow (for $\mu = 0$) in the limit when μ ultimately vanishes. In other words, if we concieve of a series of similar flow-models with gradually diminishing viscosity, is it likely that for the fluids for which viscosity is vanishingly small the flow pattern is very nearly the stream-line perfect-fluid pattern of classical hydrodynamics? One prima facie objection seems to lie in the fact that the boundary conditions in the two cases are entirely (qualitatively) different and as such no such transition is obvious.

It is being gradually realised that the impossibility of a continuous transition from the one type to the other through $\mu \to 0$ is a fact (Hpoff, 1950; Truesdell, 1950) but the reason does not lie in the difference in the boundary conditions for the two cases. On the contrary the impossibility of the transition, except through the state of no motion, is inherent in the very nature of the Navier Stokes equations. In the present note we have sought to establish this point, for the steady two-dimensional motion of a viscous incompressible fluid.

The solutions of the two-dimensional Navier-Stokes equations.

The two-dimensional steady motion of a viscous incompressible fluid is represented by

$$\psi_y \nabla^2 \psi_x - \psi_x \nabla^2 \psi_y = \nu \nabla^4 \psi, \quad .. \quad .. \quad .. \quad (1.1)$$

where ψ stands for the stream-function and ν represents the coefficient of kinematic viscosity, (μ/ρ). Using

$$\zeta = \nabla^2 \psi \quad .. \quad .. \quad .. \quad .. \quad (1.2)$$

we write (1.1) as

$$\psi_y \zeta_x - \psi_x \zeta_y = \nu \nabla^2 \zeta. \quad .. \quad .. \quad .. \quad (1.1a)$$

ζ being $\zeta(x,y)$ in general, we can, for the moment, regard (1.1*a*) as a first order differential equation in ψ and if

$$\zeta \neq 0, /\text{const.}, \quad .. \quad .. \quad .. \quad .. \quad (1.3)$$

obtain the allied equation as

$$\frac{dy}{\zeta_x} = \frac{-dx}{\zeta_y} = \frac{d\psi}{\nu \nabla^2 \zeta}. \quad .. \quad .. \quad .. \quad .. \quad (1.4)$$

One obvious integral of this equation being

$$\zeta = \text{const.}, \qquad .. \quad .. \quad .. \quad .. \quad (1.5)$$

another integral of (1.4) is obtained as

$$\psi = \nu \int_{\zeta = \text{const.}} \frac{\nabla^2 \zeta}{\zeta_x} \, dy, \qquad .. \quad .. \quad .. \quad (1.6)$$

where the integration is carried along any curve $\zeta = \text{const.}\ (c)$. Now, it is well-known that the general solution for ψ is obtained by replacing the constant c by the variable ζ after integration and adding any arbitrary function of ζ. Thus, we have, generally,

$$\psi = \nu U(\zeta, y) + F(\zeta), \qquad .. \quad .. \quad .. \quad (1.7)$$

(where the meaning of $U(\zeta, y)$ is obvious) except in the case where ζ either vanishes or is a constant everywhere. [If $\zeta_x = 0$, we can write a similar integral in terms of ζ and x.] Thus we see that the solutions of the equation (1.1) fall into two different sets. The first set corresponds to the two conditions represented by the equations (1.3) and (1.2) and relates to the cases where the motion is either irrotational ($\zeta = 0$) or the vorticity is uniform throughout ($\zeta = \text{const.}$).

The second set corresponds to the two conditions represented by the equations (1.7) and (1.2) and relates to the cases where the vorticity is variable everywhere and is neither zero nor uniform over any finite region. Thus the two sets of solutions must be mutually exclusive.

Now if we suppose that we start with a motion represented by (1.7) [and, of course, with (1.2)] and proceed to the limit $\mu \to 0$, we shall naturally arrive at the type of motion represented by

$$\left.\begin{aligned} \psi &= F(\zeta) \\ \zeta &= \nabla^2 \psi \end{aligned}\right\} \qquad .. \quad .. \quad .. \quad .. \quad (1.8)$$

where ζ is neither a constant nor zero, but must be variable in every part of the fluid previously undergoing the second type of motion described above.

Thus we conclude that a viscous shear flow with a non-uniform vorticity cannot reduce to a potential flow, or for the matter of that, a flow with uniform vorticity in the limit when μ, the coefficient of viscosity tend to zero.

It would be useful to point out that the solutions corresponding to the first set do not depend upon μ explicitly and hence the question of taking such solutions to the limit $\mu \to 0$ does not arise.

2. The Geometrical Analysis.

It is possible to arrive at the same conclusion by making an explicit use of the condition of no-slip on the boundary. We shall illustrate this point by considering the case of a fixed circular cylinder in a flow where the velocity at infinity is U.

We know, that in the case of a *perfect fluid* streaming past the circular cylinder $r = a$ with the centre at origin the stream function is given by

$$= Uy\left(1 - \frac{a^2}{r^2}\right). \qquad (2.1)$$

The stream-lines for the flow, are well-known, and the flow is characterised by the following features.

(i) The stream-lines are symmetrical about both axes and the flow on the upper half of the x-y plane gives the flow on the lower half by its reflection on the

axis of x. Hence for the purpose of a description it is enough to consider only the flow on the upper half.

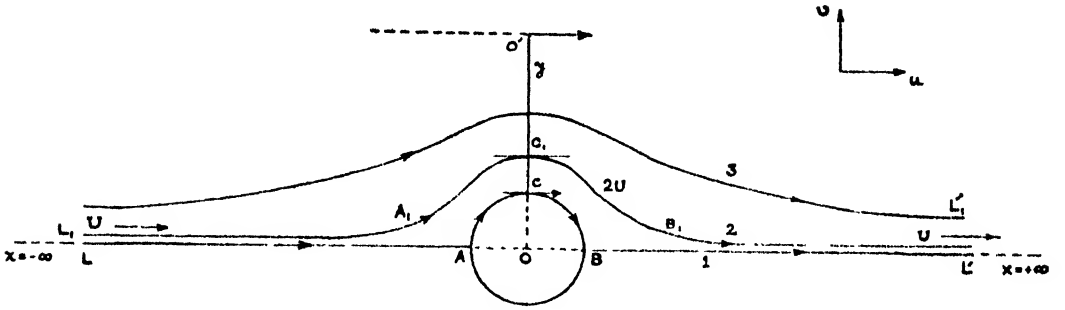

FIG. 1

(ii) At all points on the y-axis, $v = 0$ and u changes continuously from its maximum value $2U$ on the surface of the body at C (Fig. 1) to U at infinity (O').

(iii) Supposing we follow the stream-line $\psi = 0$ ($LACBL'$ in Fig. 1) from the point $L(-\infty, 0)$ to the point $L'(+\infty, 0)$, u diminishes continuously from U at $-\infty$ to 0 at A, the forward stagnation point, and $v = 0$ throughout this range: then, as we proceed along the cylindrical surface u, v both increase but by the time we reach C v vanishes again and u attains the maximum value $2U$. The same course is repeated backwards from C to B but v is negative throughout this range whereas u continues to be positive everywhere. At B again both u and v vanish and then whereas v remains zero, u increases continually to U at $L'(+\infty)$.

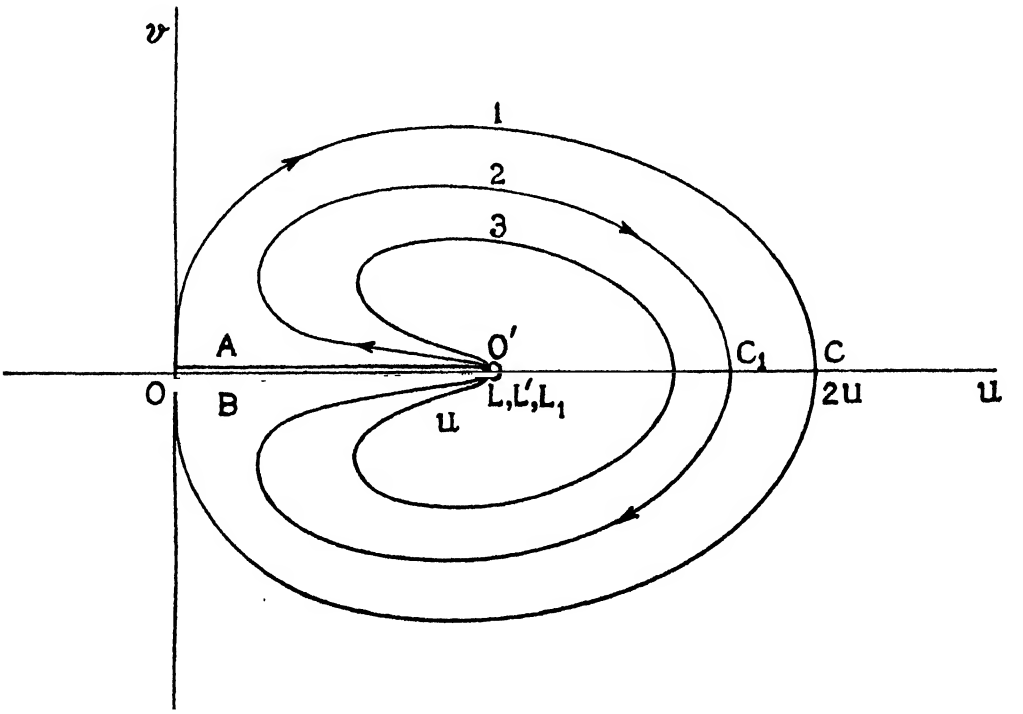

FIG. 2

(iv) A similar course is followed along any other stream-line $L_1A_1C_1B_1L_1'$ with u attaining its maximum value ($< 2U$) at C_1 and never vanishing anywhere; v vanishes only at $-\infty$, $+\infty$ and C_1. We now consider that the same phenomenon is represented in the u-v plane and we represent the stream-lines 1, 2, 3, of the x-y plane on this u-v plane by the lines 1, 2, 3. This result is roughly shown in Fig. 2.

The essential features are (Fig. 2).

(i) The entire motion on the upper half of the x-y plane is represented on the right half $u > 0$ of the u-v plane.

(ii) The line $\psi = 0$ starts from $O'(U, 0)$, moves to the origin ($u = 0$, $v = 0$) corresponding to A, runs along the arc $O\,1\,C$ and gets back to the origin for B and thence moves along the u-axis to O' again.

(iii) Every other stream-line starts from the same point O' and completes the loop at O' again.

(iv) The entire flow in the x-y plane is confined in the u-v plane within the curve $O'O\,1\,CCOO'$ corresponding to $\psi = 0$ and symmetrical about the u-axis.

(v) All stream-lines are heart-shaped loops touching each other at their common navel $O'(U, 0)$, the stream-line at infinity reducing itself to a point-curve about O'. Now, we consider that if the liquid instead of being perfect were a viscous one it should have had the following characteristics.

(1) Symmetry about the x-axis, as in Fig. 1.

(2) Symmetry about the y-axis, (at least far away from the body).

(3) The velocity at infinity is, still U everywhere.

(4) The velocity along the stream-line $\psi = 0$ changes, as before, between $-\infty$ and A but $u = 0$, $v = 0$ along the whole arc from A to B through C (Fig. 1). Hence whereas the body-surface in the perfect-fluid motion is represented by the loop $O\,1\,CO$ (Fig. 2) in the u-v plane, the same should reduce to merely the origin ($u = 0$, $v = 0$) in the case of the viscous flow. This means that the hodograph-plane representation of the viscous flow must be entirely outside the trace of the body in the same plane whereas in the perfect-fluid motion it is totally inside the same.

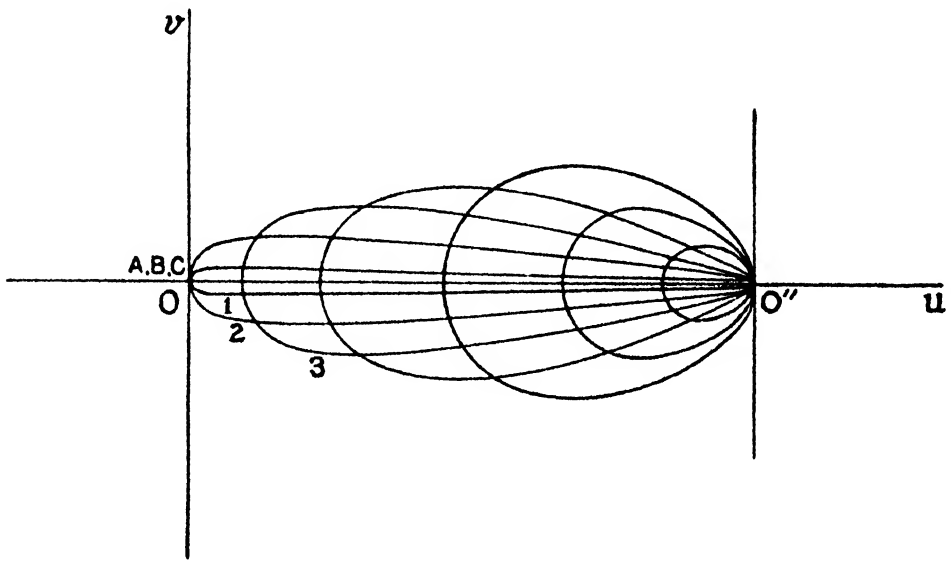

FIG. 3

(5) The velocity at all points on $x = 0$ (where $v = 0$) between C and $(O, +\infty)$ should now gradually increase from O to U and as such, the motion in the u, v

plane should be confined between $O < u < U$. Also v must have a finite maximum somewhere; assuming that it is $\pm V$ we can say that the motion must be confined within $O < u < U$, $-V < v < V$.

The stream-line at infinity is a pt. loop round $O''(U, O)$ (Fig. 3), the other lines also forming loops all touching at O'' again. As, in this case, the surface of the body need not be a stream-line, much will depend on the disposition of the stream-line through C. If it coincides with $\psi = 0$ of the perfect fluid motion, i.e. it coincides with the surface of the body, there will be an obvious indeterminacy in drawing the stream-lines close to the body in the u-v plane, for the expanding and flattening loops (Fig. 3) must stop flattening somewhere, contract sidewise and get back to merge into the st. line $O''OO''$ (Fig. 3).

On the other hand, if this stream-line, i.e., the one through C, does not coincide with the surface of the body entirely (Fig. 4), say it is $PQCRS$. Then the loops

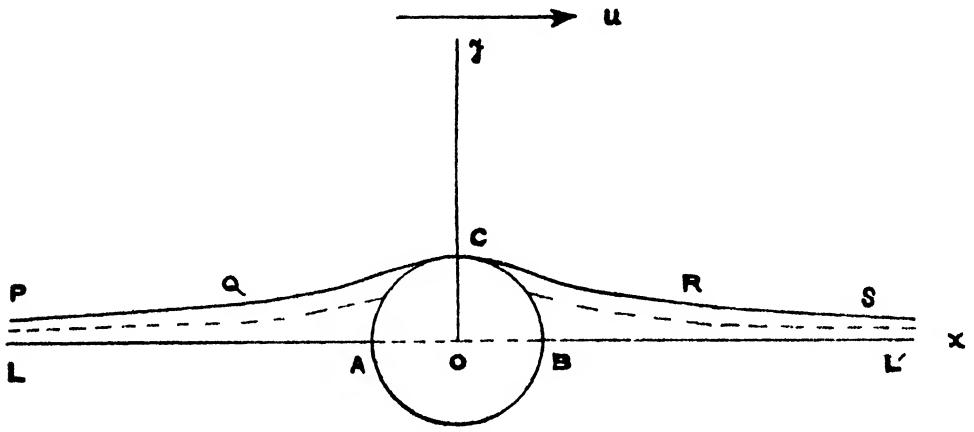

FIG. 4

expand until the largest one corresponding to $PQRS$ cut the u-axis at the origin perpendicularly. (Fig. 5). But in such a case the entire fluid between $PQRS$ (in

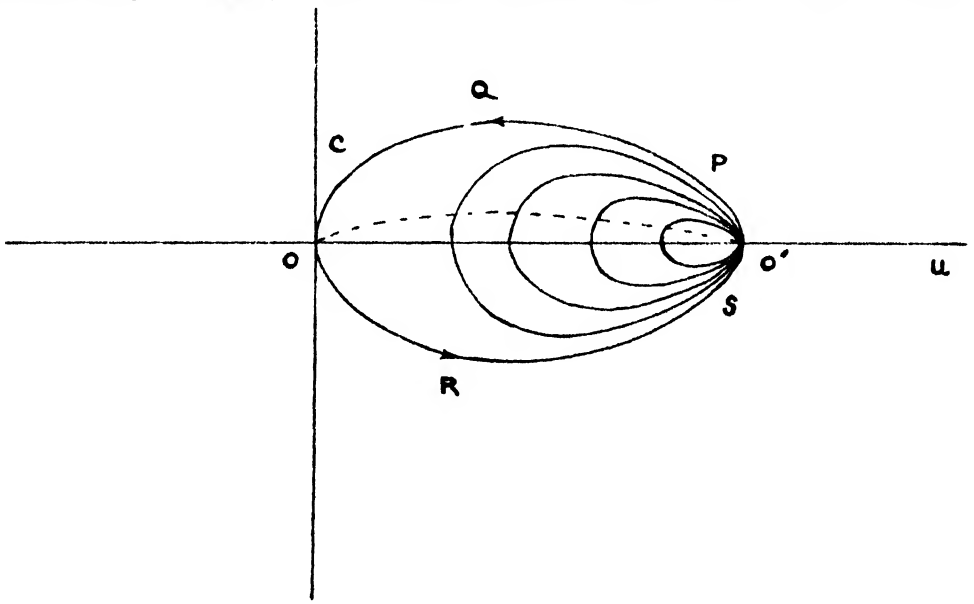

FIG. 5

the x-y plane) and the axis of y will perforce be rendered stagnant, relative to the body.

We have brought in this elaborate description to point out, incidentally, the lack of uniqueness in the adjustment of the no-slip condition.

However, the plain fact stands that whereas in the perfect fluid motion, the flow in the u-v plane is entirely confined within the trace of the boundary in the u-v plane, the no-slip condition throws the flow in the u-v plane outside the body and it is not possible to see how one system can be transformed into the other by a process of continuous transition.

Abstract.

Observation of real fluid motions are admitted to reveal potential motion away from a solid obstacle. Prandl explained this on the hypothesis that away from the body viscosity does not come into play appreciably and the fluid behaves as a perfect one. This paper seeks to investigate the type of motion that is left when a viscous fluid with initial rotational motion ultimately loses its viscosity. It proves conclusively that a non-potential motion cannot reduce to a potential motion in the limit when $\mu \to 0$, a result that was not exactly unknown.

Some geometrical evidence has been brought to bear upon the same point, by considering the motion in the hodograph plane, i.e. the (u, v) plane.

Acknowledgment.

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NOTE ON A CLASS OF EXACT SOLUTIONS OF THE TWO-DIMENSIONAL FLOW PROBLEM FOR A VISCOUS INCOMPRESSIBLE FLUID.

By Dr. N. L. Ghosh, *Research Fellow, N.I.S.I., Department of Applied Mathematics, Calcutta University.*

(Communicated by Prof. N. R. Sen, F.N.I.)

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Part I.

Introduction.

Problems on steady viscous liquid flow have been solved for a few cases where the non-linearity of the equations practically disappear as in the case of motion between two parallel plates or Poiseuille motion or motion between two cylinders, etc., mostly known as the Couette motions. Two other known exact solutions without any approximating assumptions are those of Hammel and Kármán (Goldstein, 1950) when the non-linear inertia-force terms exist. Stokes exact solutions apply to motions only very slow and Oseen's approximations are, after all, approximations and even as such are not free from defects (Lamb, 1932). The author, interested in the problem of motion of a viscous liquid past a solid of finite dimensions, has noted that the Couette types are only particular cases of a more general form. This present note seeks to construct such types of exact solutions. In part I of this note it has been shown that in the case where the vorticity is a function of the stream-function ψ_1, of the corresponding potential motion, it is possible to construct a general expression for the stream-function ψ, which will satisfy the boundary conditions. All flows, however, will not admit such types of solutions. The Couette motions on the other hand are all particular cases of this type.

Part 2 constructs the types of flow where the stream-function is a function of the same ψ_1 only. Some simple applications, by way of illustration, follow.

1. *The fundamental Equation.*

The stream-function for the steady two-dimensional Navier-Stokes equation for a liquid is given by

$$\psi_y \nabla^2 \psi_x - \psi_x \nabla^2 \psi_y = \nu \nabla^4 \psi, \qquad \ldots \qquad \ldots \qquad \ldots \qquad (1.1)$$

where the suffixes denote the corresponding partial derivatives and

$$\nabla^2 \equiv \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}.$$

We know, in such a case, the vorticity

$$\zeta \equiv \frac{\partial u}{\partial y} - \frac{\partial v}{\partial x}$$

is given by

$$\zeta = \nabla^2 \psi, \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \qquad (1.2)$$

and hence (1.1) can be written as

$$\psi_y \zeta_x - \psi_x \zeta_y = \nu \nabla^2 \zeta. \quad .. \quad .. \quad .. \quad (1.3)$$

2. *Transformations.*

Confining our attention to those problems of specified boundaries, where the flow may extend to infinity if necessary, let us suppose that the corresponding potential flow of a perfect fluid with the same boundaries is known. Let ϕ_1, ψ_1, represent the velocity potential and the stream-function respectively for such a flow and let q_1 denote the magnitude of the velocity at any point due to such a flow. Then, we know that

$$q_1^2 = \psi_{1x}^2 + \psi_{1y}^2 = \phi_{1x}^2 + \phi_{1y}^2$$
$$= |\nabla \psi_1|^2 \text{ or } |\nabla \phi_1|^2 \quad .. \quad .. \quad .. \quad (2.1)$$

and

$$\nabla^2 \phi_1 = \nabla^2 \psi_1 = 0. \quad .. \quad .. \quad .. \quad (2.2)$$

Now, the two equations giving the values of ϕ_1, ψ_1 at any point (x, y) in the plane of flow, may be solved for x and y to give

$$x = x(\phi_1, \psi_1); \quad y = y(\phi_1, \psi_1). \quad .. \quad .. \quad .. \quad (2.3)$$

In other words, instead of the Cartesian co-ordinates (x, y) we can use the system of curvilinear co-ordinates (ϕ_1, ψ_1) and they are quite suitable for the purpose because we know that the system of curves $\phi_1 = \text{const.}$ and $\psi_1 = \text{const.}$ are orthogonal at any point and $\frac{\partial(\phi_1, \psi_1)}{\partial(x, y)} \neq 0$.

With such a system it can be easily shown that

$$\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} = q_1^2 \left(\frac{\partial^2}{\partial \phi_1^2} + \frac{\partial^2}{\partial \psi_1^2} \right)$$

i.e.,

$$\nabla^2 = q_1^2 \nabla_1^2, \quad .. \quad .. \quad .. \quad .. \quad (2.4)$$

where

$$\nabla_1^2 = \frac{\partial^2}{\partial \phi_1^2} + \frac{\partial^2}{\partial \psi_1^2} \quad .. \quad .. \quad .. \quad .. \quad (2.4a)$$

Hence, from (1.2)

$$\zeta = q_1^2 \nabla_1^2 \psi. \quad .. \quad .. \quad .. \quad .. \quad (2.5)$$

Now, the basic equation (1.3) when transformed by (2.3) takes the form

$$\frac{\partial \psi}{\partial \psi_1} \cdot \frac{\partial \zeta}{\partial \phi_1} - \frac{\partial \psi}{\partial \phi_1} \cdot \frac{\partial \zeta}{\partial \psi_1} = \nu \nabla_1^2 \zeta. \quad .. \quad .. \quad .. \quad (2.6)$$

3. *Solutions.*

We consider now that type of motion which is characterized by

$$\zeta = f(\psi_1). \quad .. \quad .. \quad .. \quad .. \quad (3.1)$$

Obviously, (2.6) reduces to

$$-\frac{\partial \psi}{\partial \phi_1} \cdot f'(\psi_1) = \nu f''(\psi_1). \quad .. \quad .. \quad .. \quad (3.2)$$

This equation can obviously be integrated partially with respect to ϕ_1 giving

$$\psi = -\nu \frac{f''(\psi_1)}{f(\psi_1)} \cdot \phi_1 + F(\psi_1), \quad .. \quad .. \quad .. \quad (3.3)$$

where $F(\psi_1)$ is any arbitrary function so far. The relation (3.3) is of course subject to the condition (1.2) which, in the new system of co-ordinates, has reduced to (2.5).

Putting

$$\frac{f''(\psi_1)}{f'(\psi_1)} = \xi(\psi_1) \quad .. \quad .. \quad .. \quad .. \quad (3.4)$$

we have (3.3) as

$$\psi = -\nu\xi(\psi_1) \cdot \phi_1 + F(\psi_1). \quad .. \quad .. \quad .. \quad (3.5)^*$$

From (3.5) it is clear that

$$\frac{\partial^2\psi}{\partial\phi_1^2} = 0$$

and hence we have

$$\nabla_1^2\psi = -\nu\xi''(\psi_1)\phi_1 + F''(\psi_1)$$

and hence from (2.5) and (3.1) we must have

$$q_1^2\{-\nu\xi''(\psi_1)\phi_1 + F''(\psi_1)\} = \zeta = f(\psi_1). \quad .. \quad .. \quad (3.6)$$

Thus, for a given $f(\psi_1)$, $F(\psi_1)$ has to be determined from (3.6), provided a solution exists.

Equation (3.6) can be written as

$$\frac{1}{q_1^2} = -\nu\frac{\xi''(\psi_1)}{f(\psi_1)} \cdot \phi_1 + \frac{F''(\psi_1)}{f(\psi_1)}$$

and hence generally it is of the form

$$\frac{1}{q_1^2} = A(\psi_1)\phi_1 + B(\psi_1). \quad .. \quad .. \quad .. \quad .. \quad (3.7)$$

Now q_1^2 is assigned by the specifications of the boundary and may not be of the form (3.7); in such a case, the method cannot be applied.

If, however, q_1^2 admits of the form (3.7) formula (3.5) will represent the stream function if the value of $F(\psi_1)$ as given by (3.6) is substituted in (3.5).

Admitting such a possibility we notice that the boundary condition can be very easily adjusted.

For instance, the usually accepted boundary conditions are (Kampé de Fériét, 1948) $\psi = 0$ and $\Delta\psi = 0$ on the surface of the body.

Now, as, in the potential motion, ψ_1 vanishes on the boundary of the body, we may define the boundary in the viscous problem by $\psi_1 = 0$,
and hence, the boundary conditions must be

$$\psi = 0, \ \Delta\psi = 0 \text{ on } \psi_1 = 0. \quad .. \quad .. \quad .. \quad (3.8)$$

These are satisfied if

$$\left.\begin{aligned} \xi(0) = 0, \ F(0) = 0 \\ \xi'(0) = 0, \ F'(0) = 0 \end{aligned}\right\} \quad .. \quad .. \quad .. \quad (3.9)$$

and

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* A formula of the type (3.5) was arrived at independently by Prof. R. Ballav in course of his investigations on superposability, as reported in the Indian Science Congress, 1952.

Conditions (3.9) however can be relaxed. For the only physical condition rigorously necessary for a solution is that the velocity must vanish on the boundary. This is secured entirely if

$$\xi(0) = 0, \quad \xi'(0) = (0), \quad F'(0) = 0.$$

4. *Couette Motions.*

It may be easily seen that all Couette motions belong to the type for which $q_1^2 = q_1^2(\psi_1)$. This is a particular case of equation (3.7) where $A(\psi_1)$ vanishes. We shall discuss by way of illustration, some flows of this type at the end of part 2 of this note.

Part II.

5. With the same system of co-ordinates (ϕ_1, ψ_1) as in Art. 2 we now suppose that ψ, the stream-function for the viscous flow, is given by

$$\psi = f(\psi_1). \qquad .. \quad .. \quad .. \quad .. \quad (5.1)$$

We shall take the equation of motion to be given by (2.6) and (2.5) as before; but in this case (2.5) reduces to

$$\zeta = q_1^2 f''(\psi_1) \qquad .. \quad .. \quad .. \quad .. \quad (5.2)$$

and hence

$$\nabla_1^2 \zeta = q_1^2 f^{iv}(\psi_1) + 2 \frac{\partial q_1^2}{\partial \psi_1} \cdot f'''(\psi_1) + f''(\psi_1) \cdot \nabla_1^2 q_1^2, \qquad .. \quad (5.2a)$$

where q_1^2 and ∇_1^2 are given, as before, by (2.1) and (2.4a). With (5.2a), (2.6) reduces to

$$f'(\psi_1) f''(\psi_1) \cdot \frac{\partial q_1^2}{\partial \phi_1} = \nu \left\{ q_1^2 f^{iv}(\psi_1) + 2 \frac{\partial q_1^2}{\partial \psi_1} \cdot f'''(\psi_1) + f''(\psi_1) \cdot \nabla_1^2 q_1^2 \right\} \cdot \quad .. \quad .. \quad (5.3)$$

Integrability of the equation (5.3).

It may be noted that, in general, q_1^2 can be regarded as a function of both ϕ_1 and ψ_1. The function f being purely a function of ψ_1, it becomes apparent that the validity of the equation (5.3) for all values of ϕ_1 and ψ_1 will impose certain restrictions on q_1^2. These restrictions will really specify the types of flow which may admit of a solution of the form (5.1). For, for a given set of boundary specifications, the potential motion of the perfect-fluid flow is uniquely determined (Dirischlet flow) and so is q_1^2. When the value of q_1^2 thus obtained makes (5.3) integrable, the corresponding solution may be obtained. If not, there is no solution of the type for the assigned specifications.

It is obvious that when q_1^2 is either a constant or a function of ψ_1 alone, the equation (5.3) can always be integrated and hence costruction of a solution of the type (5.1) is always possible in these cases, provided the boundary conditions are satisfied by the resulting function.

6. *The Boundary Conditions.*

As before, we shall take the boundary of the solid to be defined by $\psi_1 = 0$ and hence for the no-slip condition (3.8) must hold. Now in this case, from (5.1), we have

$$\nabla\psi = f'(\psi_1) \cdot \nabla\psi_1, \qquad .. \quad .. \quad .. \quad .. \quad (5.4)$$

and hence, as $|\nabla\psi_1| \neq 0$ on $\psi_1 = 0$

$$f'(0) = 0. \qquad .. \quad .. \quad .. \quad .. \quad (5.4a)$$

If in addition, we consider that the fluid extends to infinity and flows there with a uniform velocity U, $|\nabla\psi_1| \to U$ when $\psi_1 \to \infty$. Hence, in order that the same condition may hold for the viscous flow we must have,

$$f'(\infty) = 1. \qquad .. \quad .. \quad .. \quad .. \quad (5.4b)$$

Thus, a function f, satisfying (5.3) and the conditions (5.4*a*) and (5.4*b*), (provided the integrability condition for the corresponding q_1^2 is satisfied) will lead to an exact solution of the viscous flow problem.

It has been noticed that the viscous flow past a circular cylinder does not admit of a solution of the type (5.1); for the corresponding q_1^2 for the potential flow does not render (5.3) integrable.

We shall discuss briefly, by way of illustration, two particular cases, the solutions for which are already well-known.

6. *Case* (1): $q_1^2 = U^2 =$ a const.

The viscous problem corresponding to this case is that of the motion of a viscous liquid past a plane wall, say $y = 0$. The stream function for the corresponding potential motion is given by $\psi_1 = Uy$ and hence (5.1) makes ψ a function of y alone. As, further, q_1^2 is a constant (5.3) reduces to

$$f^{iv}(\psi_1) \equiv f^{iv}(y) = 0, \qquad .. \quad .. \quad .. \quad (6.1)$$

the general solution of which is

$$\psi = a_0 + a_1 y + a_2 y^2 + a_3 y^3. \qquad .. \quad .. \quad .. \quad (6.2)$$

Now, as, $y = 0$ when $\psi_1 = 0$ and $y \to \infty$ when $\psi_1 \to \infty$, the boundary conditions (5.4a) and (5.4b) reduce in this case to

$$\psi(0) = 0, \ \psi'(\infty) = 1. \qquad .. \quad .. \quad .. \quad (6.3)$$

The latter condition cannot obviously hold and hence the solution cannot apply to a flow extending to infinity. We shall therefore consider only the case of flow between two planes $y = 0$ and $y = h$. We may think of two cases; (i) when both planes are fixed and (ii) when one is fixed and the other moving with a uniform velocity V.

In general, from (6.2)

$$u = \frac{\partial\psi}{\partial y} = a_1 + b_1 y + c_1 y^2, \text{ say.} \qquad .. \quad .. \quad (6.4)$$

Case (*i*). The boundary conditions are

$$u = 0 \quad \text{when} \quad y = 0 \quad \text{and} \quad y = h.$$

Hence the solution is

$$u = c_1 y(y - h). \qquad .. \quad .. \quad .. \quad .. \quad (6.5)$$

Case (*ii*). If $y = 0$ be fixed and $y = h$ moving with a uniform velocity V, we must have

$$\left.\begin{aligned} u &= 0 \quad \text{on} \quad y = 0 \\ u &= V \quad \text{on} \quad y = h \end{aligned}\right\} \qquad .. \quad .. \quad .. \quad .. \quad (6.6)$$

and hence (6.4) gives

$$u = \frac{Vy}{h} + \frac{c_1 y(y-h)}{h}, \quad .. \quad .. \quad .. \quad .. \quad (6.7)$$

quite a well-known result. [Lamb, (1932), p. 583.]

7. *Case 2.* $q_1^2 = q_1^2(\psi_1)$: *Motion round a circular cylinder.*

When a perfect fluid undergoes a motion of circulation round a circular cylinder, $r = a$, with the velocity vanishing at infinity, we know,

$$\psi_1 = k \log \frac{r}{a}. \quad .. \quad .. \quad .. \quad .. \quad (7.1)$$

Hence,

$$q_1^2 = |\nabla \psi_1|^2 = \left(\frac{k}{a}\right)^2 e^{-2\psi_1/k} \quad .. \quad .. \quad .. \quad (7.2)$$

and so,

$$\frac{\partial}{\partial \phi_1} q_1^2 = 0. \quad .. \quad .. \quad .. \quad .. \quad (7.2a)$$

The surface of the cylinder is given by $r = a$ and, hence, by

$$\psi_1 = 0, \quad .. \quad .. \quad .. \quad .. \quad (7.3)$$

and hence, the *inner* boundary condition for the viscous flow, must be

$$f'(0) = 0. \quad .. \quad .. \quad .. \quad .. \quad (7.4)$$

Now putting,

$$q_1^2 = Q(\psi_1) \quad .. \quad .. \quad .. \quad .. \quad (7.5)$$

and

$$f''(\psi_1) = P(\psi_1), \quad .. \quad .. \quad .. \quad .. \quad (7.6)$$

we have from (5.3)

$$\frac{d^2}{d\psi_1^2}(PQ) = 0, \quad .. \quad .. \quad .. \quad .. \quad (7.7)$$

which gives, at once,

$$PQ = A + B\psi_1; \quad .. \quad .. \quad .. \quad .. \quad (7.8)$$

and so,

$$f''(\psi_1) = (C + D\psi_1)e^{2\psi_1/k}, \quad .. \quad .. \quad .. \quad (7.9)$$

where

$$\left.\begin{aligned} C &= \left(\frac{a}{k}\right)^2 . A \\ D &= \left(\frac{a}{k}\right)^2 B. \end{aligned}\right\} \quad .. \quad .. \quad .. \quad .. \quad (7.10)$$

Integrating (7.9) and applying (7.4) we have

$$f'(\psi_1) = \frac{k}{2} e^{\frac{2\psi_1}{k}} \left\{C + D\left(\psi_1 - \frac{k}{2}\right)\right\} - \frac{k}{2}\left\{C - \frac{k}{2}D\right\}. \quad .. \quad (7.11)$$

Now, the velocity at any point, ψ_1,

$$|\nabla\psi_1| = |f'(\psi_1)| \cdot |\nabla\psi_1| = \frac{k}{a} \cdot e^{-\frac{\psi_1}{k}} \cdot f'(\psi_1), \quad \ldots \quad \ldots \quad (7.12)$$

from (7.2), and hence we notice that the velocity at infinity can neither vanish nor tend to a finite limit, and so the motion considered cannot extend to infinity.

On the other hand, for appropriate values of C and D the solution can be fitted to the case of fluid rotating between two circular cylinders $r = a$, $r = b$ $(a < b)$, the inner of which is fixed and the outer rotating with a finite angular velocity. It is also possible to adjust the solution to the case when the inner cylinder is rotating and the outer is fixed but in such a case the boundary condition (7.4) has to be modified accordingly.

These cases have been treated otherwise so thoroughly and simply (Lamb, 1932, p. 588) that it will serve no useful purpose to go into the details of their discussion.

Abstract.

This paper contains two parts. In part I an exact solution of the boundary value problem for the two-dimensional viscous fluid motion has been formulated in the special case when the vorticity is a function of the stream function ψ_1, of the corresponding potential motion with the same boundary, alone. It has been found that such special cases are restricted by a particular form for the square of the velocity in the potential motion. The exact solutions without approximating hypothesis that have been so far obtained, viz., the Couette motions—are however covered by this general investigation.

In the second part, investigations have been carried on into another type of cases—the class of problems where the stream-function ψ of the viscous motion is, again, a function of ψ_1, of the corresponding potential motion, alone. The ordinary differential equation obtained is of the fourth order and generally non-linear and carries its own limitations of applicability. Two examples from the known Couette motions have been appended to illustrate its possible utility.

Acknowledgment.

The work has been carried on under the Research Fellowship scheme of the National Institute of the Sciences of India in the laboratory of Prof. N. R. Sen, Ghose Professor of Applied Mathematics, Calcutta University and the author takes this opportunity to offer his grateful thanks to the N.I.S.I. and to Prof. Sen.

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NATIONAL INSTITUTE OF SCIENCES OF INDIA

(Publication Section)

NOTICE

BULLETINS

National Institute of Sciences of India

The Institute has decided to publish the proceedings of the various Symposia, held from time to time, in a separate series of publication, known as the *Bulletins,* of which No. 1 containing the proceedings of the Symposium on "The Rajputana Desert", held in March, 1952, has been published.

It has been decided that the Members of Council, NISI, will get this as well as subsequent issues of the *Bulletins* **free,** while the Fellows of the Institute will also get each a copy free on request made to:

The Secretary, National Institute of Sciences of India,
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28th November, 1952

THE COMPLEX BAND SPECTRUM OF DIATOMIC MANGANESE CHLORIDE IN THE VISIBLE REGION.

By P. TIRUVENGANNA RAO, *I.C.I. Research Fellow, N.I.S.I., Department of Physics, Andhra University, Waltair.*

(Communicated by Dr. K. Rangadhama Rao, F.N.I.)

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INTRODUCTION.

Characteristic bands due to diatomic molecule manganese chloride are known to occur in four spectral regions (1) around λ 2500, (2) between λ 3500 and λ 4000, (3) λ 4300–λ 4600, and (4) between λ 4800 and λ 5100. Following Bacher (1948), these four systems may be designated as α, β, γ' and γ respectively. A complete analysis of the β system showed that the transition is a $^7\Pi$–$^7\Sigma$, while the α system with a simpler structure is suggested by Bacher to arise in a $^7\Sigma$–$^7\Sigma$ transition, with $^7\Sigma$ as the ground state common to both the systems. Mention was also made by him of the existence of another system γ in MnCl, MnBr and MnF, which was suggested as an intercombination system due to the transition $^5\Pi$–$^7\Sigma$ involving the lower state as the ground state $^7\Sigma$. For both γ and γ' systems, only measurements of a few diffuse bands as reported by Mesnage are just available in the literature. The present paper deals with the results obtained by the author in a detailed study of these two systems.

EXPERIMENTAL.

The spectrum was excited in a heavy current discharge from a 2,000-volt D.C. generator using a fused silica discharge tube of special design, which was described previously by the author (1949). This source was found suitable for the excitation of the spectra of the halides of such refractory elements as manganese, chromium, iron, cobalt and nickel. For photographing the spectrum, a Fuess glass spectrograph of high light gathering power was employed as the band systems γ and γ' are comparatively weaker than the others. The dispersion of the instrument is about 25–30A° per mm. in the region under investigation. A higher dispersion instrument is found unsuitable for a good reproduction of the two systems. Exposures varying from half a minute to 2 minutes' duration were given employing Ilford Selo-chrome plates.

STRUCTURE AND ANALYSIS OF THE γ SYSTEM.

Plate XIV$_{(a)}$ is a reproduction of the γ system in the region between λ 4800 and λ 5100. The bands are apparently arranged in four groups which may be designated as groups I, II, III and IV respectively starting from the red end. It was found that the wavenumber intervals between certain prominent bands in the neighbourhood of λ 4977·8 in group III and those of group I around λ 5075 are approximately equal to the vibrational frequency 384·7 of the ground state of MnCl. This at once suggested that groups II and III, which stand out prominently and are well developed, may form the $\Delta v = 0$ sequence and groups I and IV the $\Delta v = -1$ and $+1$ sequences respectively. A closer examination of the plates revealed that there are some line-like bands between groups II and III which lent further support to the view that the members of the two groups form the $\Delta v = 0$ sequence. Some of the bands in the various groups are red-degraded while others are line-like.

Bacher also reported that the $\Delta G(v'')$ intervals in the γ system of MnCl, MnBr and MnF suggest that the ground state is the lower state of the system. From a comparison of the electronic transitions in Mn atom with those of MnH, MnF, MnCl, MnBr and MnI, he suggested that the γ system which occurs only in emission and with comparatively less intensity than the other systems, may be an intercombination system arising in the transition $^5\Pi$–$^7\Sigma$. It is shown in the present paper that it is possible to interpret the structure of the $\Delta v = 0$ sequence of the γ system of MnCl on the basis of a $^5\Pi$–$^7\Sigma$ transition.

The possible rotational heads for the transition $^5\Pi$ $^7\Sigma$ may be formulated as follows. The ground state $^7\Sigma$ corresponds to Hund's coupling case (b). In a Σ state ($\Lambda = 0$), there is a spin splitting of each rotational level, i.e. for each value of K there will be 7 component levels with $J = K+S$ to $J = K-S$, which following Mulliken, may be designated as F_1, F_2....F_7 respectively. The separations of these levels are not ordinarily resolvable. The upper $^5\pi$ state may belong to case (a) or (b) or an intermediate state between the two. In fact, it approaches case (a) for low values of K and case (b) for higher values of K. For case (a) we get by combining Λ with Σ, five levels $^5\pi_{-1}$, $^5\pi_0$, $^5\pi_1$, $^5\pi_2$ and $^5\pi_3$ which in case (b) on account of the spin splitting will become F_5, F_4, F_3, F_2 and F_1 levels respectively. For each value of K there will be five values of J and the selection rules are that $\Delta J = 0$ or ± 1 and ΔK can be either 0 or ± 1 or ± 2 or ± 3.

A schematic diagram for the transition $^5\Pi$–$^7\Sigma$ representing the various expected branches is represented in Fig. 1. The form of the branches is indicated in the usual notation $T\ S\ R\ O\ P\ Q\ N$ corresponding to ΔK values of $+3$, $+2$, $+1$, 0, -1, -2, and -3 respectively. The rotational lines can be represented by the formula

$$\begin{aligned} \nu &= \nu_0 + F'(K) - F''(K) \\ &= \nu_0 + B'K'(K'+1) - B''K''(K''+1) \end{aligned}$$

where ν_0 represents the frequency of the null line of the band. The formulae for the individual forms are

Form	ΔK	
T	$+3$	$\nu = \nu_0 + F'(K+3) - F''(K)$
		$= \nu_0 + 12B' + (7B' - B'')K + (B' - B'')K^2$
S	$+2$	$\nu = \nu_0 + F'(K+2) - F''(K)$
		$= \nu_0 + 6B' + (5B' - B'')K + (B' - B'')K^2$
R	$+1$	$\nu = \nu_0 + F'(K+1) - F''(K)$
		$= \nu_0 + 2B' + (3B' - B'')K + (B' - B'')K^2$
Q	0	$\nu = \nu_0 + F'(K) - F''(K)$
		$= \nu_0 + (B' - B'')K + (B' - B'')K^2$
P	-1	$\nu = \nu_0 + F'(K-1) - F''(K)$
		$= \nu_0 - (B' + B'')K + (B' - B'')K^2$
O	-2	$\nu = \nu_0 + F'(K-2) - F''(K)$
		$= \nu_0 + 2B' - (3B' + B'')K + (B' - B'')K^2$
N	-3	$\nu = \nu_0 + F'(K-3) - F''(K)$
		$= \nu_0 + 6B' - (5B' + B'')K + (B' - B'')K^2$

Differentiating the above expressions with respect to K and equating to zero (the condition for head formation) we get K_h, the value of K at which the head is formed. For the case in which $B'' > B'$ (red-degraded bands) K_h is positive for R, S, T forms and negative for the others if as usually the case $3B' > B''$. The K_h values for the latter are shown below.

ΔK	0	$+1$	$+2$
Form	Q	R	S
K_h	0	$\dfrac{3B' - B''}{2(B'' - B')}$	$\dfrac{5B' - B''}{2(B'' - B')}$

Hence in the present system of MnCl we expect only the Q, R, S forms only as head-forming. These transitions are shown in Fig. 1.

TABLE I.

MnCl bands. γ System.

Sequence.	Wavelength. A°	Wavenumber cm.$^{-1}$	I	v', v''	ΔJ		
					-1	0	$+1$
$\Delta v = -1$	5086·5	19654·4	4				
,,	5078·4	19685·8	9	0,1	$^{Q}P_{5}$	Q_{56}	$^{Q}R_{57}$
,,	*5075·0	19699·0	5	0,1	$^{R}P_{54}$	$^{R}Q_{5}$	R_{56}
,,	5066·9	19730·5	2				
$\Delta v = 0$	5041·7	19829·1	6				
,,	5037·2	19846·8	7	0,0	$^{Q}P_{1}$	Q_{12}	$^{Q}R_{13}$
,,	5033·6	19861·0	5	0,0		$^{R}Q_{1}$	R_{12}
,,	*5029·8	19876·0	6	0,0			$^{S}R_{1}$
,,	5025·4	19893·4	7	1,1	$^{Q}P_{2}$	Q_{23}	$^{Q}R_{24}$
,,	5021·2	19910·0	4	0,0	$^{Q}P_{2}$	Q_{23}	$^{Q}R_{24}$
,,	5018·8	19919·5	6	0,0	$^{R}P_{21}$	$^{R}Q_{2}$	R_{23}
,,	5015·2	19933·8	4	0,0		$^{S}Q_{21}$	$^{S}R_{2}$
,,	5013·2	19941·8	6				
,,	5007·3	19965·3	4	0,0	$^{Q}P_{3}$	Q_{34}	$^{Q}R_{35}$
,,	*5004·8	19975·3	4	0,0	$^{R}P_{32}$	$^{R}Q_{3}$	R_{34}
,,	4998·3	20001·2	4				
,,	4991·0	20030·5	7	0,0	$^{R}P_{43}$	$^{R}Q_{4}$	R_{45}
,,	4981·5	20068·7	8	0,0	$^{Q}P_{5}$	Q_{56}	$^{Q}R_{57}$
,,	4977·8	20083·6	10	0,0	$^{R}P_{54}$	$^{R}Q_{5}$	R_{56}
$\Delta v = +1$	4900·8	20399·2	3	1,0	$^{R}P_{43}$	$^{R}Q_{4}$	R_{45}
,,	4891·3	20438·8	5	1,0	$^{Q}P_{5}$	Q_{56}	$^{Q}R_{57}$

* Bands superposed by Mn lines.

With the aid of the scheme of expected transitions in a $^{5}\Pi$–$^{7}\Sigma$ as shown in Fig. 1, the vibrational and rotational assignments of band heads were made as shown in Table I. The subscripts given in the last column relate to the numbering of F levels in the upper and lower states. For each of the spin rotational levels, the P, Q, R branches of the same form are not ordinarily resolvable even under high dispersion and therefore the same band is assigned for the three branches.

Plate XIV$_{(a)}$ shows the main head-forming R branches ($\Delta K = \Delta J = +1$) R_{56}, R_{45}, R_{34}, R_{23}, R_{12} of the $\Delta v = 0$ sequence. The interval separations between these heads as shown in Table II indicates that the coupling constant A is of the order of 56 cm.$^{-1}$.

TABLE II.

v', v''	R_{56}		R_{45}		R_{34}		R_{23}		R_{12}
0, 0	20083·6	53·1	20030·5	53·2	19975·3	55·8	19919·5	58·5	19861·0

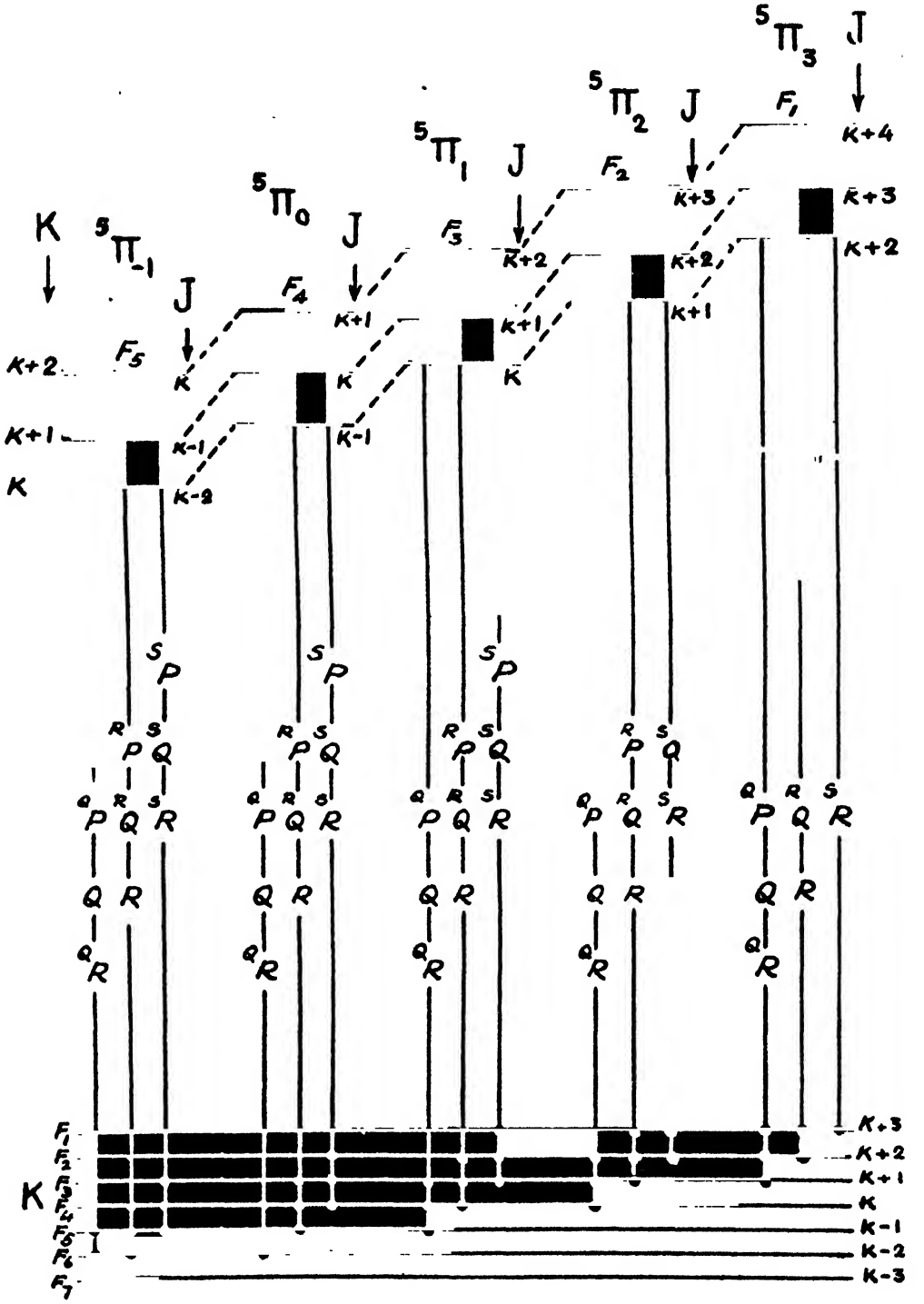
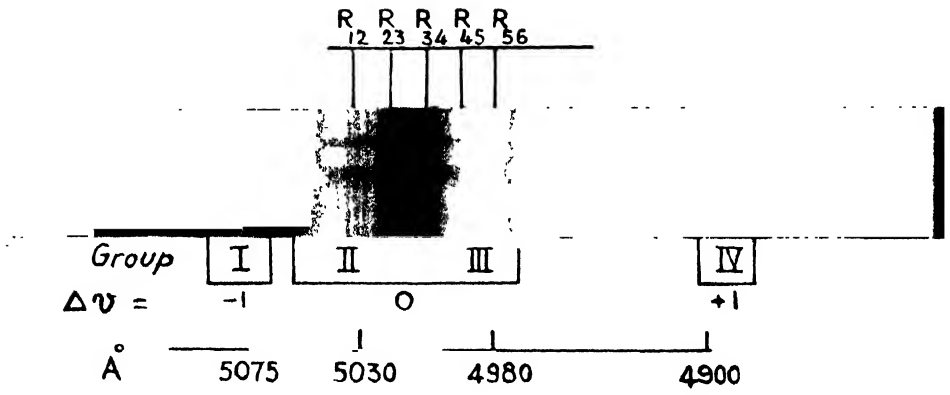
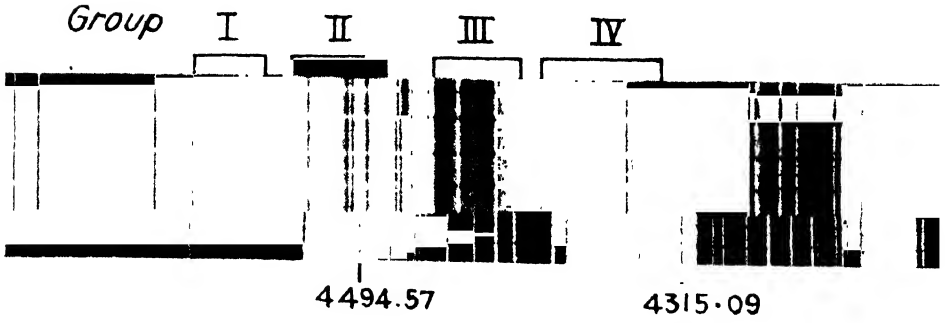


Fig. 1.

Scheme of transitions in $^6\Pi$–$^7\Sigma$ when $^6\pi$ is intermediate between case (*a*) and (*b*).



(b)



MnCl bands.

I(*a*). γ system.
I(*b*). γ' system.

With a multiplicity of 5 for the upper state, the overall width of the multiplet is $4 \times 56 = 224$ cm.$^{-1}$ Hence there should be no overlapping of band heads of the $\Delta v = 0$ sequence with those of the $\Delta v = -1$ sequence. This feature is also evident from the reproduction. The multiplet analysis was shown in detail in the case of band heads of the $\Delta v = 0$ sequence as the development of $\Delta v = -1$ and $+1$ sequences is poor. From the observed $\Delta G(v)$ intervals as shown in Table III, the following approximate vibrational constants were derived for the system :

$$\omega_e' = 370 \text{ cm.}^{-1}$$

$$\omega_e'' = 384 \text{ cm.}^{-1}$$

TABLE III.

$\Delta K = \Delta J$ Heads v', v''	R_{56}	Q_{56}
0, 0	20083·6	20068·7
	384·6	382·9
0, 1	19699·0	19685·8
$\Delta K = \Delta J$ Heads v', v''	Q_{56}	R_{45}
0, 0	20068·7	20030·5
	370·1	368·7
1, 0	20438·8	20399·2

The γ' system of MnCl.

Plate XIV$_{(b)}$ is a reproduction of the γ' system occurring in the region between λ 4300 and λ 4600. It consists of four groups which, starting from the red end, may be designated as groups I, II, III and IV respectively. Some of the bands seem to be degraded towards the red while some are headless and others are diffuse. It is not possible to interpret the structure of this system owing to the poor development of sufficient number of band heads in any group. However, a wavenumber interval of approximately 384 cm.$^{-1}$ is observed between certain prominent bands of groups I and II as shown in Table II. This suggests that the ground state $^7\Sigma$ may be the lower state of the system.

TABLE IV.

Group II.		Group I.
22302·3		21917·9
	384·4	
22184·5		21800·4
	384·1	
22166·3		21782·3
	384·0	

As the groups are not well developed, only a catalogue of the band heads is given in Table V.

TABLE V.

MnCl bands. γ′ System.

Group.	Wavelength.	Intensity.	Wavenumber.
I	4595·0(*R*)	2	21756·7
,,	4589·6	2	21782·3
,,	4585·8	8	21800·4
,,	4569·3	3	21879·1
,,	4561·2	5	21917·9
,,	4556·8	3	21939·1
,,	4551·4	5	21965·1
II	4514·9(*R*)	6	22142·7
,,	4510·1	3	22166·3
,,	*4506·4	7	22184·5
,,	4482·6(*R*)	10	22302·3
III	4468·0(*R*)	4	22375·1
,,	4463·6	3	22397·2
,,	4427·4(*R*)	10	22580·3
,,	4423·8	3	22598·7
,,	4421·7	2	22609·4
,,	4405·7	5	22691·5
IV	4383·5(*D*)	5	22806·4
,,	4354·0(*V*)	4	22961·0
,,	4346·5	4	23000·6
,,	4329·8	4	23089·3
,,	4326·0	3	23109·6

* Band superposed by Mn line.
R—Red-degraded. *V*—Violet-degraded. *D*—Diffuse.

ABSTRACT.

The emission spectrum of diatomic manganese chloride is excited in a heavy current discharge through the vapour and photographed in the visible region using a Fuess glass spectrograph. Two systems designated here as γ and γ′ were obtained more extensively than those reported by Mesnage. The γ system occurring in the region λ 4800–λ 5100 has been interpreted on the basis of a $^6\pi$–$^7\Sigma$ transition involving terms of high multiplicity. The vibrational constants ω_e' and ω_e'' were approximately obtained as 370 cm.$^{-1}$ and 384 cm.$^{-1}$ respectively.

Measurements of 22 bands occurring in four groups of the γ′ system were given and a recurring wavenumber interval of 384 cm.$^{-1}$ between some bands is also indicated.

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ULTRA VIOLET BANDS OF MERCURY IODIDE MOLECULE, PART V.

By C. RAMASASTRY, *D.Sc., Department of Physics, Indian Institute of Technology, Kharagpur.*

(*Lately I.C.I. India Research Fellow, N.I.S.I., Andhra University, Waltair.*)

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The emission spectrum of diatomic mercury iodide radical is very extensive stretching from λ 4500 to λ 2100. As many as twelve different systems of discrete bands are reported in the literature. The author has previously analysed four band systems H, G, F_3 and F_1 (Ramasastry and K. R. Rao, 1947 and Ramasastry, 1948), commencing from the short-wave length end of the spectrum. The group of bands lying in the region λ 2450–λ 2380, designated as system F_2, will now be considered.

Through the work of M. G. Sastry (unpublished) and Ramakrishnarao and K. R. Rao (1946) the existence of this band system was established. The latter authors also gave wavelength data and indicated some regularities in an attempt to get at the vibrational analysis. In the present work the bands could be measured under a much higher dispersion of 2·4 A/mm. on quartz Littrow Spectrograms. A few additional bands obtained at the short wavelength end of the system and better resolution at the long wavelength end enabled the author to form regular series.

The F_2-system has rather a peculiar appearance. There is a large amount of crowding at the long wavelength end. This closing up could be explained as due to long progressions or sequences the interval between whose members decreases at a rapid rate. In either case the first attempt should be to find regularities from the points of view of both the intervals and intensities.

From the short wavelength end, one can easily pick out a series of bands commencing from ν 42188. This series is indicated in the first column of Table I. The development of the series is quite smooth from all points of view up to ν 41633. The approximate position of the next member is on the band ν 41564 which itself has apparently greater intensity and a smaller separation than ν 41633. On close examination it can be noticed that the band is rather broad which is attributable to the superposition of another band on the long wavelength side of ν 41564. The position and intensity of the superposed band give it a place in the first series while 41564 itself should belong to another series. Higher members of this first series which must be weaker should have been submerged in the greater intensity of the members of the other series.

The second series beginning at 41940 has also a similar ending at its fifth member ν 41602. It looks that progressions II and IV have got common regions in the neighbourhood of ν 41602, ν 41523 and ν 41455, the decreasing intensity of progression II and the increasing intensity of progression IV being approximately equal at ν 41523. On similar considerations the other series are also formed.

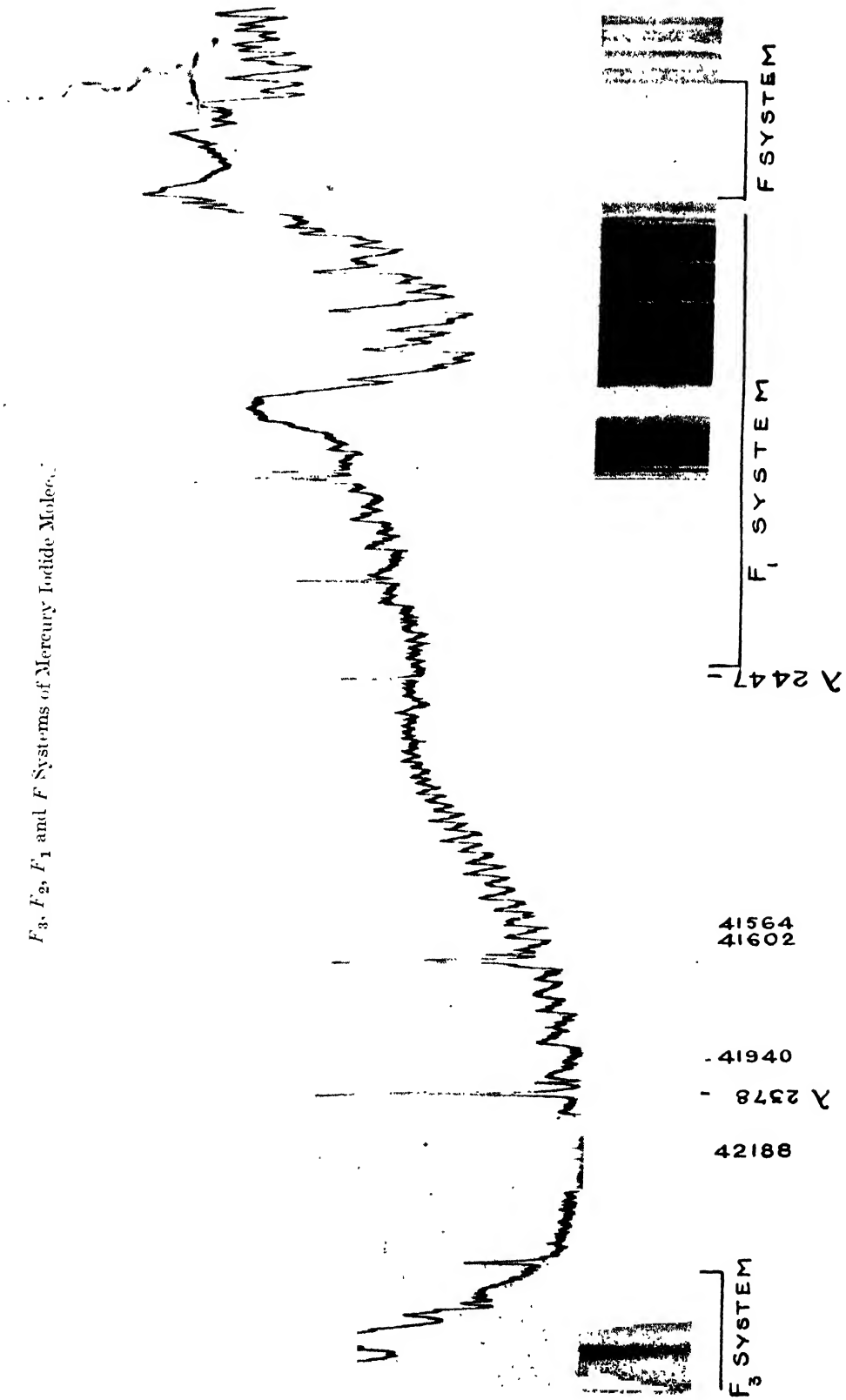
In the vibrational analysis shown in Table I, these various series are presented as lower state progressions. It would also be equally well if these are considered as sequences with the first series as the (0–0) diagonal one and the rest moved one

step higher with respect to its left side neighbour so as to represent $\Delta v = -1$, -2, -3 etc. sequences. This would give a first interval of about 150 cm.$^{-1}$ in the lower state vibrational level spacings. As this and the generalisation of intervals do not agree even approximately with those of any one of the electronic states till now analysed, such an arrangement as sequences is not favoured here.

Coming to the arrangement shown in Table I, one striking feature is that the intervals in both the upper and lower state became considerably smaller with increase of vibrational quantum number. Even if the arrangement as sequences

TABLE I.

	0		1		2		3		4		5	
		44·5		41		33		29·5		21		= 169
	42188											
97	97											
	42091											
98	98											
	41993											
95	95											
	41898	42	41940									
89·5	90		89									
	41808	43	41851									
87·5	89		86									
	41719	46	41765									
85·5	86		85									
	41633	47	41680									
78			78									
	415– –		41602									
79			79									
			41523	41	41564							
73					73							
			414– –		41491	32	41523					
68·5					69		68					
					41422	33	41455					
67					67		67					
					41355	33	41388					
62					62		62					
					41293	33	41236					
59							59					
					412– –		41269					
56							56					
							41211	31	41242			
52·5							51		54			
							41160	28	41188			
47									47			
							4111–		41141			
45									45			
									41096	22	41118	
43·5									43		44	
									41053	21	41074	
41·5									41		42	
									41012	20	41032	
36·5									36		37	
									40976	19	40995	
34									36		32	
									40940	23	40963	
34									32		36	
									40908	19	40927	
29											29	
											40898	
1458												



F_3, F_2, F_1 and F Systems of Mercury Iodide Molec[illegible]

is preferred, this closing up of levels is present. This is considered as due to the proximity of these vibrational levels to their respective dissociation limits. If the same average rate of convergence at 3 cm.$^{-1}$ per quantum number in the lower state continues, the dissociation limit for the lower state would be reached in about 11 more steps with a total energy of 145 cm.$^{-1}$ approximately. The sum of the 23 observed levels being 1458 cm.$^{-1}$, the dissociation energy above the first observed vibrational level of the lower state is about 1603 cm.$^{-1}$ (or a little more if ionic forces of inverse square law type prevail near the dissociation limit in the case of such molecules as the Mercury halides). Similarly, for the upper state its dissociation limit should lie about 196 cm.$^{-1}$ above the first vibrational level of that state.

NATURE AND IDENTIFICATION OF THE ELECTRONIC STATES.

The upper state is thus very shallow and could house about 10 vibrational levels only before dissociation sets in. Besides the low vibrational frequency of about 50 cm.$^{-1}$ compared to the lower state frequency of about 98 cm.$^{-1}$, would also indicate an electronic state with a small binding force and the potential minimum in the $U(r)-r$ curve must be situated at large internuclear distance. The large displacement of the shallow minimum of the P.E. curve of the upper state can explain the observation of lower state vibrational progressions near its dissociation limit as the vertical lines from the outer extremities of the vibrations in the upper state would then fall in the vicinity of the dissociation limit of the lower state. If a transition were to take place between the dissociation limits of the two states, the energy would be $42188+196-1603 = 40781$. This should correspond to $\nu_{atom.}$ An examination of the atomic energy states of mercury and iodine gives that $6s6p\ ^3P_0$ (Hg)$-6s9s\ ^1S_0$ (Hg) gives 40759, indicating that the dissociation products for the lower and upper states are $6P\ ^3P_0$ (Hg)$+^2P_{3/2}$(I) and $9S\ ^1S_0$ (Hg)$+^2P_{3/2}$(I). Probably the electronic transition is between first excited state and a very highly excited state of the HgI molecule. The small discrepancy of 22 cm.$^{-1}$ is probably due to uncertainty in the extrapolation of the lower state, then the dissociation limit of the lower state may be taken to be located about 1625 cm.$^{-1}$ above the first observed vibrational level of that state in the F_2-system. If as reported by Wieland (1948), the first excited electronic state of HgI (upper state of the system B of visible bands) has $w_0 = 110$, the v'' quantum number for the 42188 band can be fixed to be at 4 using the $x_e w_e$ value of 3 obtained from the present analysis; this leads to a value of $110+107+104+101+1625 = 2047$ cm.$^{-1}$ for the dissociation energy of the upper state B of the visible bands which is identified as the lower state for the F_2-system.

On the other hand, if it is assumed that the lower state of the F_2-system is the ground state of the molecule itself ($w_e'' = 125{\cdot}7$ and $x_e''w_e'' = 1{\cdot}1$) despite the lack of agreement of the derived $\nu_{atom.}$ of 40805 with any of the energy levels of the mercury and iodine atoms measured from their ground levels of $6s^2\ ^1S_0$ (Hg) and $5p^5\ ^2P_{3/2}$, the sum of the first 9 vibrational levels would be 1024 as the average from the analyses of H, G and F systems. The interval between the 8th and 9th levels is 105 cm.$^{-1}$ only so that it can reach 98 cm.$^{-1}$, the first interval observed in the lower state of the F_2-system, in two steps. This gives a v' quantum number of 12 for 42188 and a dissociation energy of $1024+203+1603 = 2830$ cm.$^{-1}$ as compared with $\frac{w_e^2}{4x_e w_e} - \frac{1}{2} w_e = 3496$ cm.$^{-1}$. From the predissociation limit observed in the H-system at 47350 cm.$^{-1}$ (Ramasastry and K. R. Rao, 1947), the upper limits for two probable values of dissociation energy are 3310 cm.$^{-1}$ and 2110 cm.$^{-1}$. Neither of which agree with the above value of 2830 cm.$^{-1}$ which represents the lower limit. Because of these discrepancies it is considered more probable

to identify the lower state of the F_2-system with the upper state of the B-system of visible bands.

The author is indebted to Prof. K. R. Rao for his interest in the work and to Dr. D. S. Kothari for his encouragement. His grateful thanks are due to the National Institute of Sciences of India for the award of a I.C.T. (India) Research Fellowship.

Abstract.

The F_2-system of HgI bands lying in the region 2450A–2380A are photographed on the Hilger Medium and Littrow Quartz Spectrographs. About 40 bands could be measured. The closing up of the bands towards the long wavelength end is explained by a vitrational analysis which includes six lower state progressions. The vitrational level intervals in the lower state decrease from 98 to 30 cm.$^{-1}$ in about 22 steps and those of the upper state from 44 to 21 cm.$^{-1}$ in 4 steps leading to extrapolated dissociation limits of 1603 cm.$^{-1}$ and 220 cm.$^{-1}$ respectively above the lowest observed vitrational levels. It is suggested that the band system may not involve the ground state but may be due to a transition between two excited states.

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Wieland, (1948). Molecülspectren mit Ionencharakter und ihre Beeinflussung durch Fremdgase 'Contribution a l'etude de la structure Moleculaire', 229–238.

(*a*) and (*b*) Two positives of a heavily exposed Spectrogram (Medium Quartz).
(*c*) Positive from a Quartz Littrow Spectrogram.

ON THE ZEROS OF A CERTAIN POLYNOMIAL.

By A. Sharma, *M.A., Ph.D., Lucknow University.*

(Communicated by Dr. S. M. Shah, F.N.I.)

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1. Recently Venkataraman (1950) has generalized a result of Prof. K. S. K. Iyer and has shown that the zeros of any section of the power series for e^z, say

$$\frac{1}{r!}+\frac{z}{(r+1)!}+\ldots\ldots+\frac{z^n}{(r+n)!}$$

lie in the region $(r+1) < |z| < (r+n)$.

In an attempt to generalize this result, I have proved a similar property for any section of the power-series for $\left(\frac{e^x-1}{x}\right)^r$ and the power-series

$$\sum_{n=0}^{\infty}(n+\alpha)^r\frac{x^n}{n!}.$$

The object of this note is to prove a similar theorem when formally

$$\left(\frac{(1-x)^{-h}-1}{x}\right)^r=\sum_{n=0}^{\infty}p_n(r)x^n, \qquad (h>1) \qquad .. \qquad .. \quad (1)$$

and r is a positive integer.

I shall prove that the zeros of

$$P(z)=\sum_{k=0}^{n}p_{m+k}(r)z^k$$

lie in the region

$$\frac{p_m(r)}{p_{m+1}(r)} < |z| < \frac{p_{m+n-1}(r)}{p_{m+n}(r)}$$

2. In order to prove this result, we shall first prove the following lemmas :—

Lemma 1. The functions $p_n(r)$ satisfy the following relation—

$$(n+r)p_n(r)=(n+r+hr-1)p_{n-1}(r)+hrp_n(r-1), \qquad (n>1) \qquad .. \quad (2)$$

This is proved easily by multiplying (1) by x^r and differentiating. A little rearrangement gives (2).

Lemma 2. The functions $p_n(r)$ satisfy the inequality

$$\frac{p_n(r)}{p_{n+1}(r)} < \frac{p_{n+1}(r)}{p_{n+2}(r)}, \qquad \text{for } \begin{matrix} n=1,2,\ldots.; \\ r=1,2,\ldots.. \end{matrix} \qquad .. \qquad .. \quad (3)$$

To prove this we observe that from the known relations

$$p_0(r) = h^r, \quad p_n(1) = \binom{n+h}{n+1}$$

$$p_n(r+1) = \sum_{\lambda=0}^{n} p_\lambda(r)\, p_{n-\lambda}(1)$$

we can prove the inequality (3) by induction on r. For $r = 1$, the inequality is easily verified.

3. *Proof of the main Theorem :*

(i) Write

$$\alpha = p_m(r)/p_{m+1}(r).$$

Then

$$(\alpha - z)P(z) = \alpha p_m(r) - \left[\sum_{k=0}^{n-1} \{ p_{m+k}(r) - \alpha p_{m+k+1}(r) \} z^{k+1} + p_{m+n}(r) z^{n+1} \right].$$

By Lemma 2,

$$p_{m+k}(r) - \alpha p_{m+k+1}(r) > 0,$$

so that for $|z| < \alpha$,

$$\left| \sum_{k=0}^{n-1} \{ p_{m+k}(r) - \alpha p_{m+k+1}(r) \} z^{k+1} + p_{m+n}(r) z^{n+1} \right| < \alpha p_m(r).$$

Hence

$$|(\alpha - z)P(z)| > 0$$

i.e. all the zeros of $P(z)$ lie in $|z| > \alpha$.

(ii) Now put

$$\beta = p_{m+n-1}(r)/p_{m+n}(r)$$

and let

$$g(z) = z^n P\left(\frac{\beta}{z}\right) = b_0 z^n + b_1 z^{n-1} + \ldots + b_n.$$

Then for $|z| < 1$,

$$|(1-z)g(z)| > b_n - |\{(b_n - b_{n-1})z + \ldots + (b_1 - b_0)z^n + b_0 z^{n+1}\}| > 0,$$

since by lemma 2, $b_r > b_{r-1}$, $(r = 1, 2, \ldots, n-1)$ and $b_n = b_{n-1}$. Thus $|g(z)| > 0$ if $|z| < 1$ and hence $|P(z)| > 0$ if $|z| > \beta$.

Hence the zeros of $P(z)$ lie in $\alpha \leqslant |z| \leqslant \beta$.

4. Lastly in a similar order of ideas, we shall state the following theorem :—

Assume that a_m, c_m are each > 0, $n \geqslant 0$, and that

$$a_m^2 > a_{m-1}\, a_{m+1}, \quad c_m^2 > c_{m-1}\, c_{m+1}, \qquad \text{for } m \geqslant 1.$$

Put

$$\left(\sum_{m=0}^{\infty} a_m z^m \right) \left(\sum_{m=0}^{\infty} c_m z^m \right) = \sum_{m=0}^{\infty} A_m z^m.$$

Then for $m = 1, 2, \ldots.$

$$A_m^2 > A_{m-1} A_{m+1}.$$

This theorem is easily proved on observing that

$$A_m = \sum_{\lambda=0}^{m} a_{m-\lambda} c_\lambda.$$

This theorem is more general than a Lemma of Polya (1950).

I take this opportunity to thank Prof. S. M. Shah for his kind suggestions.

Abstract.

An attempt is made in this paper to consider the zeros of sections of the power series expansion of $\left(\frac{(1-x)^{-h}-1}{x}\right)^r$ where r is a positive integer and $h > 1$. The result is connected with an interesting theorem of Polya.

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SKELETON OF CYPRINOID FISHES IN RELATION TO PHYLOGENETIC STUDIES.

III. The Skull and other skeletal structures of Homalopterid Fishes.

By L. S. Ramaswami, *Senior Research Fellow, N.I.S.I., Department of Zoology, Central College, Bangalore.*

(Communicated by Dr. S. L. Hora, D.Sc., F.N.I.)

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Introduction.

In a comparative account of the skull of a few Homalopterid species and of a Gastromyzonid example given by me (Ramaswami, 1948), it was pointed out that the phylogeny of the Homalopteridae including the Gastromyzonidae could not be discussed as I had not examined the Cyprinid and Cobitid genera which are the probable progenitors of the two groups.

Subsequently a number of Homalopterid and Gastromyzonid genera was made available to me by Dr. S. L. Hora, Director, Zoological Survey of India, Calcutta, and I thank him for the generous gift of the material. I propose to examine four genera of Homalopteridae (*sen. stric.*) and place on record their cranial and other osteological characters with a view to elicit their origin and affinities.

Segemehl (1891) examined one species of *Homaloptera* (*ocellata* C.V.) and while pointing out its Cyprinid and Cobitid affinities, he cautiously refrained from coming to any conclusions with regard to the relationships of the Homalopteridae as the examination of a single species would not warrant any generalizations. In this connexion, it may also be mentioned that Regan (1929) considered the Homalopteridae widely different from the Cobitidae. More recently Berg (1947) described the family Homalopteridae as comprising the Homalopterini and Gastromyzonini. But Hora (1950) established by an examination of external characters that the original Homalopteridae including Gastromyzonidae should be split up into two independent families,—the Homalopteridae and Gastromyzonidae, as was envisaged by him previously (Hora, 1932). Among the Homalopteridae according to Hora

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ERRATA

Skeleton of Cyprinoid Fishes in relation to Phylogenetic Studies. I. The systematic position of the Genus *Gyrinocheilus* Vaillant by L. S. Ramaswami. *Proc. Nat. Inst. Sci.*, Vol. XVIII, No. 2, pp. 125–140, and II. The systematic position of *Psilorhynchus* McClelland by L. S. Ramaswami. *Proc. Nat. Inst. Sci.*, Vol. XVIII, No. 2, pp. 141–150.

Page 126, footnote: *Instead of* All figures have been drawn at a magnification of ×17 (approx.) except Figs. 10–12*a*, *read*: Figures have been drawn at a magnification of ×17; 10–12*a* are not reduced; figs. 3 and 4 are reduced to 1/3 approx. and the rest to ½ approx.

,, 136, 7th line from bottom: *read* lacrimal *for* laerimal.

,, 142, Figure 2: delete typewritten abbreviation 'tf'.

,, 144, 28th line from top: *read* Homa-lopteridae *for* Homal-opteridae.

(*op. cit.*), the genus *Homaloptera* is generalised and formed the 'starting point for the different and ultimate evolution of the other genera'. By a study of the scale structure, Law (1950) however, pointed out that *Homaloptera* was probably a heterogeneous assemblage of forms and that 'different forms of *Homaloptera* seem to have given rise to various types of Homalopterine genera'.

Material.

The following species have been studied by me:

Homaloptera zollingeri Bleeker; *H. amphisquamata* W. & de B.; *H. leonardi* Hora & Tweedie; *H. rupicola* Prashad & Mukherji; *Balitora brucei* Gray; *Balitora brucei* var. *mysorensis* Hora; *Bhavania australis* Jerdon; *Lepturichthys nicholsi* Hora.

Observations.

The ethmoid region.—In the genera of Homalopteridae examined, the supra-ethmoid portion of the ethmoid is broad and is firmly articulated with the frontals (figs. 1*a*–4*a*, 3*c fr*) posteriorly as in the cyprinids. There is a median anterior prolongation of it as in *Psilorhynchus* (Ramaswami, 1952*b*) which may be pointed as in *Balitora* (figs. 1*a*, 1*b p*) or expanded as in *Homaloptera* and *Lepturichthys* (figs. 2*a*, 3*a*, 3*c*, 4*a p*). This pointed or expanded prolongation is also seen in the ventral aspect (figs. 1*b*–4*b p*); the ethmoid is also noticed on the same aspect (figs. 1*b*–4*b et*) with whose lateral surface the palatine (*pal*) articulates in *Balitora*, *Lepturichthys*, *Homaloptera zollingeri*, *H. leonardi* and *Bhavania*. In *H. amphisquamata* peculiarly the palatine (figs. 3*a*, 3*b pal*) does not articulate with the ethmoid since the anterior preethmoid (*pet*) is elongated and thus keeps out the ethmoid. Moreover, in the same species, the supraethmoid is not broad enough so that the articulation of the elongated preethmoid with the ethmoid is clearly visible on the dorsal aspect. Sagemehl (1891) delineated an elongated second preethmoid (septomaxilla, according to him) in *Homaloptera ocellata* (fig. 1, Plate 18). Further, unlike the Gastromyzonidae, not a single species of Homalopteridae shows a slender supraethmoid portion which is therefore uniformly broad in all the genera examined.

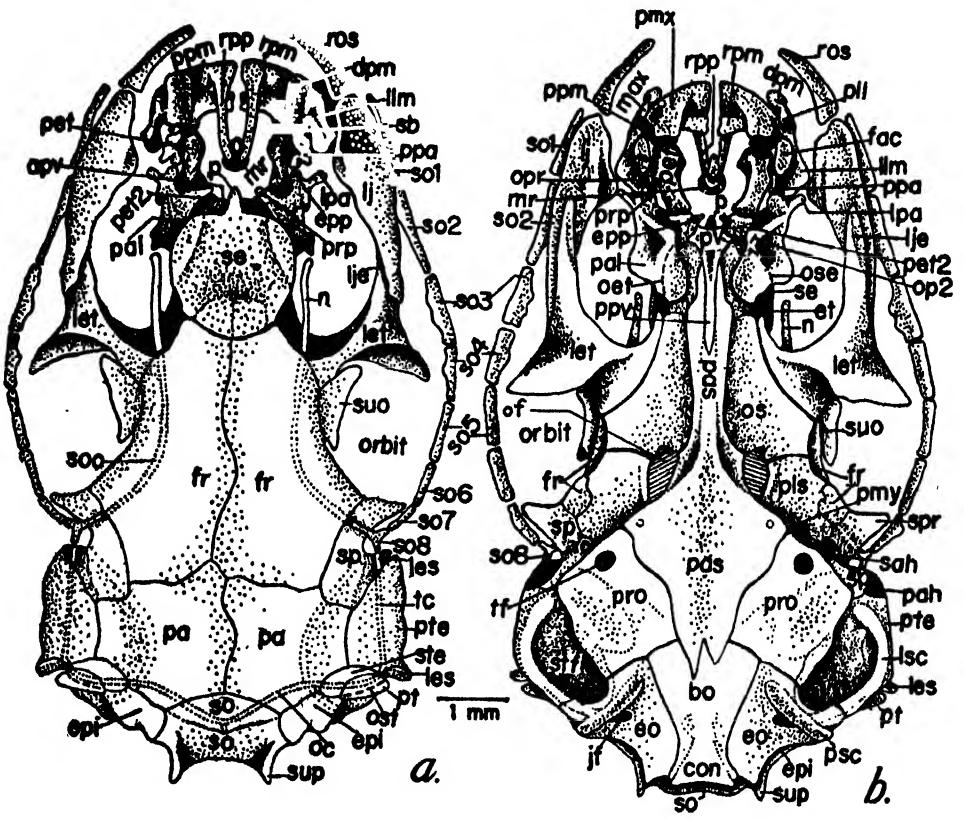
Articulating with the ethmoid and prevomer laterally in the Homalopteridae, there is a small rounded bone which has been called by previous authors like Sagemehl (1891) and Regan (1911) a 'septomaxillary'. Having taken into account the inappropriateness of the term for the bone, I labelled it as the anterior process of the ethmoid in my previous paper on the Homalopterid skull (Ramaswami, 1948). Regan (1911) describing the occurrence of this bone in Cypriniformes, noted that it was firmly united with the prevomer and that it articulated, directly or otherwise, with the maxilla anteriorly. Later Starks (1926) in describing the ethmoid region of fish skull employed the term 'preethmoid' for describing this nodule of bone in forms like *Misgurnus* etc.; in the Indian cyprinids examined by me, the bone occurs prominently and further, I have already used the term in describing the bone in *Gyrinocheilus* (Ramaswami, 1952*a*) and *Psilorhynchus* (Ramaswami, 1952*b*).

In the Homalopteridae, as in the Cobitidae examined by me, the preethmoid not only gives articulation laterally to the palatine but also to a rod of bone in front [called 'submaxillary' by Sagemehl (1891) and Regan (1911)] which connects it with the maxilla anteriorly. In my previous paper (Ramaswami, 1948) I labelled this rod of bone the preethmoid as it was disposed in front of the 'anterior process' of the ethmoid.

A study of the skull characters of the Cobitidae has enabled me now to speculate upon the possible origin of the preethmoids. It is noticed that in the Cobitidae like *Acanthophthalmus*, *Misgurnus*, *Somileptes* etc., there is an elongated

preethmoid intercalated, articulating with the maxilla anteriorly by a facet and posteriorly by facets with the prevomer ventrally, and the palatine dorsally. If this bone splitted horizontally, it would give rise dorsally to a bone situated between and articulating anteriorly with the maxilla and posteriorly with the palatine, called by me prepalatine in the present paper, and ventrally to one which articulates anteriorly with the maxilla and posteriorly with the prevomerine projection; this will be the new preethmoid. Such a condition is met with in *Botia*, one of the cobitidinid examples where a prepalatine and a preethmoid are noticed. Sagemehl (1891) however, described similar bones in the cobitid forms studied by him as 'submaxillaries'.

In the Homalopteridae it is very likely that the bones labelled by me prepalatine and preethmoid have arisen in the same way as in the Cobitidae. If so,



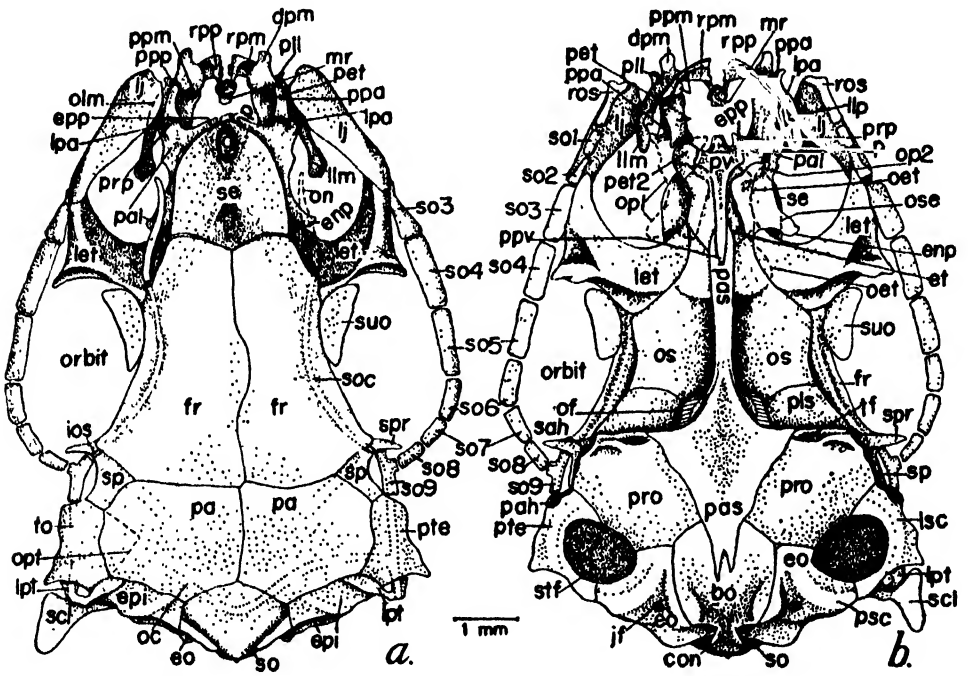
TEXT FIG. 1*a*, 1*b*. Dorsal and ventral views respectively of the skull of *Balitora brucei* var. *mysorensis* Hora; in fig. 1*a* the maxillae are gently pulled apart.

the Cobitidae and the Homalopteridae having taken their origin from a cyprinoid ancestor have evolved on parallel lines. Thus it may be that the first formed preethmoid of the early Cobitidae and of the Homalopteridae elongated and then gave rise to the prepalatine and preethmoid bones.

Probably to increase the mobility of the anterior region, some ancestral cobitids and homalopterids developed a second preethmoid as an apophysis of the antero-lateral ethmoid region (sometimes the anterior extension of the prevomer also taking part with the latter) with which the first preethmoid i.e. the preethmoid formed by the splitting of the bone referred to in *Acanthophthalmus*, etc., commenced to articulate. The preethmoid of the cyprinids therefore, may be homologous with the elongated first preethmoid and not with the second preethmoid of the

present day Cobitidae and Homalopteridae, though, at first sight, the latter appears topographically comparable with that in the Cyprinidae.

It must be pointed out here that the bones labelled by me (Ramaswami, 1948) as the lateral rostral and the preethmoid in the Homalopteridae and the Gastromyzonidae correspond to the 'submaxillaries' of Sagemehl (1891); Regan (1911) and Gregory (1933) also referred to them in the cypriniform examples described by them retaining the same nomenclature as Sagemehl. I avoided the term 'submaxillary' since topographically the bones are not disposed ventrally to the maxilla and therefore, the term 'submaxillary' was not justifiable. I have therefore ventured to designate in my present paper the bone articulating with the anterolateral corner of the ethmoid and of the prevomerine projection as the second preethmoid (figs. 1*a*–4*a*, 1*b*–4*b*, 3*c* *pet2*) and that in front of it, as the first preethmoid (*pet*). The other bone sitting on the first preethmoid and articulating with the palatine facet, which was labelled 'lateral rostral' on purely topographical grounds



TEXT FIG. 2*a*, 2*b*. Dorsal and ventral views respectively of the skull of *Homaloptera zollingeri* Bleeker; the supracleithrum is shown on one side only.

by me (Ramaswami, 1948), I now describe as the prepalatine (figs. 1*a*–4*a*, 1*b*–4*b*, 3*c* *ppa*), a term which has already been employed by Starks (1926) for describing a bone in similar location in *Siganus* studied by him.

There is usually a ligament passing from the prepalatine to the facet (figs. 2*a*, 3*a* *ppp*) of the maxilla where the prepalatine articulates. In *Balitora brucei* var. *mysorensis* there is a small sesamoid bone (fig. 1*a* *sb*) in front of the prepalatine (*ppa*).

The premaxilla of the Homalopteridae (figs. 1*a*–4*a*, 1*b*–4*b*, 3*c* *pmx*) resembles that in the Cyprinidae. There is a dorsal rostral process (*rpp*) disposed dorsally to the median rostral (*mr*). In *H. amphisquamata* the rostral process (figs. 3*a*, 3*b* *rpp*) extends beyond the median rostral (*mr*) and in *H. rupicola* (fig. 3*c* *rpp*) it rests on the anterior end of the supraethmoid. The lateral process may be short and expanded as in *Balitora* (fig. 1*b* *pmx*) or may be elongated as in *Homaloptera* (figs. 2*b*, 3*b*, *llp*), *Lepturichthys* (fig. 4*b*. *llp*) and *Bhavania*.

The homalopterid maxilla shows all the processes noticed in that of the cyprinid, viz., the dorsal premaxillary process (figs. 1*a*–4*a*, 1*b*–4*b*, 3*c dpm*), the ventral rostral process (*rpm*), the lateral process for the ligament of the adductor manidbulae muscle (*pll*) and posteriorly the prominent projections for the articulation of the prepalatine (*ppa*) and the first preethmoid (*pet*). However, in the cyprinids, the maxilla on the posterior face shows one or two facets; one of them is directed towards the preethmoid and the other towards the palatine. In *Lepturichthys*, the dorsal premaxillary process (figs. 4*a*, 4*b dpm*) is very prominent and mesially to it there is a large prominence (*pr*) whose posterior edge articulates with the first preethmoid (*pet*). In the ventral view of the skull the anterior portion of this prominence is visible as a small projection (fig. 4*b pr*) mesially to the dorsal premaxillary process (*dpm*).

The prevomer (figs. 1*b*–4*b pv*) is noticed ventrally as underlying the ethmoid (*et*) and parasphenoid (*pas*) bones. Anterolaterally, the prevomer articulates with the second preethmoid (*pet*2); in *H. amphisquamata* alone it is broad (fig. 3*b pv*) and the posteromedial limb is also short.

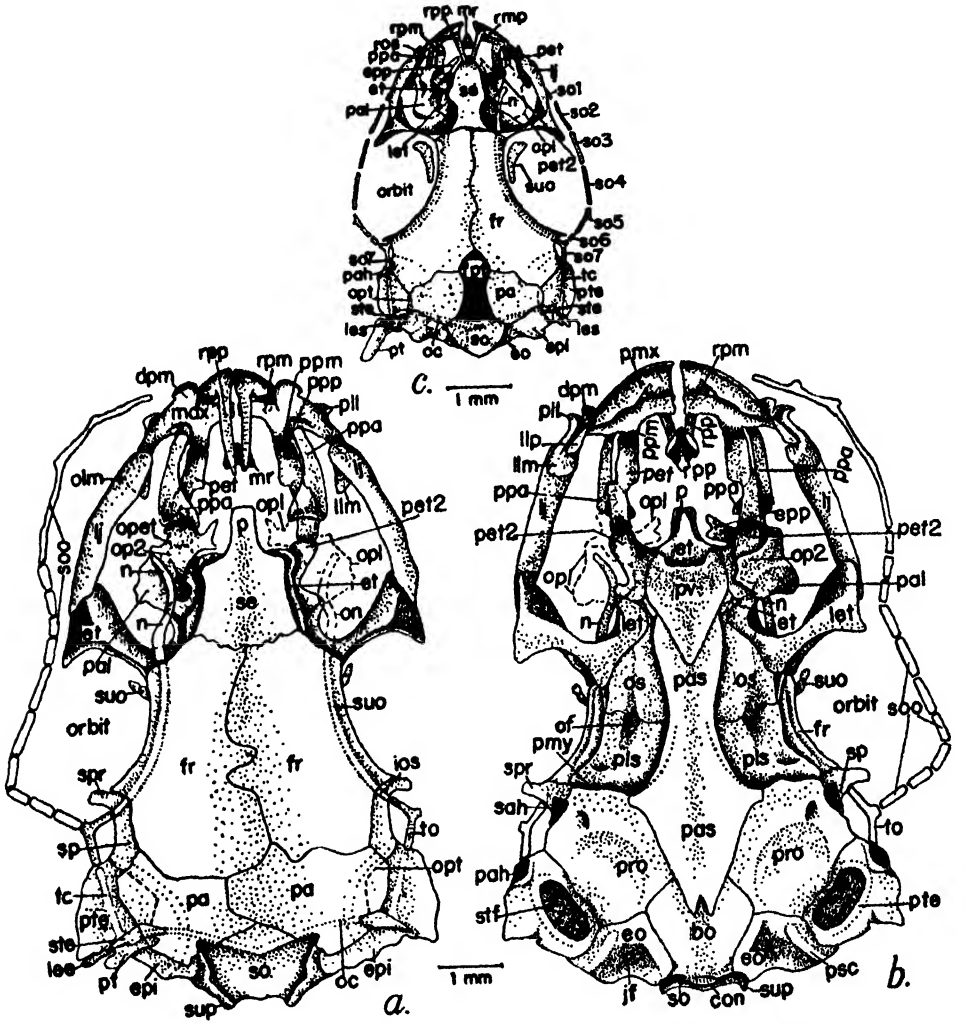
The lacrimojugal of the Homalopteridae while agreeing topographically with the lacrimal of Cyprinidae, is comparatively longer, probably formed by the fusion of a lacrimal and a posterior jugal and hence the term lacrimal is not used here. The bone (figs. 1*a*–4*a*, 1*b*–4*b*, 3*c lj*) is very large and in *Balitora* and *Lepturichthys*, and there is in front of it one (figs. 1*a*, 1*b*, 3*c ros*) or more sensory canal bones. In the latter example, I have labelled a bone (figs. 4*a*, 4*b ros*) as corresponding to the rostral of *Balitora* and associated with it mesially, there are two other sensory canal bones, probably also rostral derivatives. In *H. amphisquamata*, and *H. leonardi* the long lacrimojugal (figs. 3*a*, 3*b lj*) is not so closely associated with the canal bones as in *H. zollingeri*, so much so, it is difficult to say of the exact extension of the rostral if the latter exists at all in front of the lacrimojugal.

The lateral ethmoid (figs. 1*a*–4*a*, 1*b*–4*b* 3*c let*) separates the anterior olfactory region from the posterior orbital region. Dorsomesially it is in contact with the frontal (*fr*) and ventrally with the ethmoid (*et*), the orbitosphenoid and sometimes with the supraorbital and the second preethmoid. The lateral extension of the bone is in contact with the suborbital sensory canal ossicles and also the lacrimojugal, and projects both anteriorly and posteriorly; in *Lepturichthys* and *Balitora*, the lacrimojugal process of the lateral ethmoid (figs. 4*a*, 4*b lje*) is very much longer than the posterior process of the same. In *H. amphisquamata* the processes are short and blunt (figs. 3*a*, 3*b*) and in *H. zollingeri* (figs. 2*a*, 2*b*), *H. rupicola* (fig. 3*c*) and *Bhavania* the processes are better developed; in *H. leonardi*, they are long and broad. In *H. ocellata* also Sagemehl (1891) showed these processes as well developed.

It may be useful to describe the palatine here though it belongs to the upper jaw. The palatine (figs. 1*a*–4*a*, 1*b*–4*b*, 3*c pal*) of the Homalopteridae differs from that in the Cyprinidae in a very important feature. While as in the Cyprinidae, the palatine shows a prominent process (either pointed or rounded) (*epp*) towards the anteromesial process of the ethmoid (*et*) and articulates mesially with the second preethmoid (*pet*2) and the ethmoid (*et*) and posteriorly with the entopterygoid (*ept*), there is however, no direct articulation with the maxilla as in the cyprinids. This is because, in the Homalopteridae, the elongated first preethmoid and the prepalatine are intercalated between the maxilla (*ppm*) and the palatine (*pal*).

While in *Lepturichthys*, *Balitora*, *Bhavania* and *H. zollingeri* the prepalatine articular facet of the palatine is small, in *H. amphisquamata* (figs. 3*a*, 3*b*) it is comparatively larger. In addition in *Lepturichthys*, *H. zollingeri*, *H. rupicola* and *Balitora* the palatine shows a prominent anterolateral process (figs. 1*a*–2*a*, 1*b*–2*b*, 4*a*–4*b lpa*) projecting towards the lacrimojugal (*lj*) which I have therefore, called the lacrimojugal process. In *H. leonardi* peculiarly this lateral lacrimojugal process comes in contact with the lacrimojugal anteriorly and the posterior articulation of the prepalatine is also noticed at this region. Thus a separate prepalatine articular

facet of the palatine is not seen in *H. leonardi.* A lacrimojugal process has also been seen in a few cyprinid genera like *Cirrhina* and *Aspidoparia* studied by me. In all the Homalopterid examples studied by me, it is noticed that there is a ligamentary connexion between the lacrimojugal and the palatine process. In *Bhavania* and *H. amphisquamata* this lacrimojugal process is absent. Peculiarly in *H. amphisquamata* the mesial articulation of the palatine is not with the second preethmoid and the ethmoid as in the other Homalopteridae, but with the elongated



TEXT FIG. 3*a*, 3*b*. Dorsal and ventral views respectively of the skull of *Homaloptera amphisquamata* W. & de B.; the supraorbital sensory canal ossicles are shown on one side only and the posttemporal is drawn on the left side of the dorsal view only.

„ 3*c*. Dorsal view of the skull of *Homaloptera rupicola* Prashad and Mukherji; the posttemporal is shown on one side only.

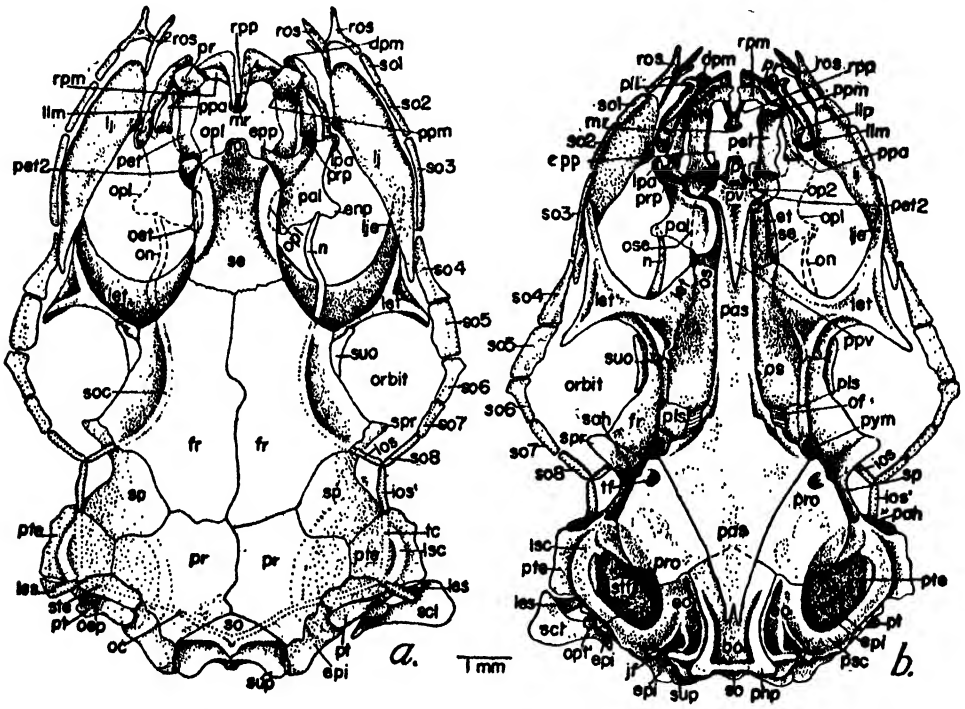
second preethmoid only which on account of its elongation has kept out the ethmoid as already remarked.

A pair of slender elongated nasal bones (figs. 1*a*–4*a*, 1*b*–4*b*, 3*c* *n*) is noticed laterally to the ethmoid in the Homalopteridae as in the Cyprinidae.

The median rostral.—In *Lepturichthys*, the dorsal aspect of the median rostral (fig. 4*a* *mr*) shows a deep depression and the rostral limbs (*rpp*) of the premaxilla

are noticed over this depression; there is also a short ventral projection from the median rostral (*mr*). While in the other examples of Homalopteridae studied, the rostral processes of the premaxillae rest on the dorsal aspect of the median rostral, in *H. rupicola*, they rest on the supraethmoid part. In *H. amphisquamata* (figs. 3*a*, 3*b*) there are two lateral processes for attachment of the ligament from the ventrolateral process of the maxilla. Obviously the median rostral shows variations in its structure within the family itself.

The orbitotemporal region.—On account of the general depression of the head, the frontals (figs. 1*a*–4*a*, 1*b*–4*b*, 3*c fr*) and parietals (*pa*) are large. In *Homaloptera*, however, the widening of the frontals is not so great as in the other examples, particularly in the region of the lateral ethmoid. The lateral extensions of the frontals become visible in the ventral aspect also; this is seen to the maximum extent in *Lepturichthys* (fig. 4*b fr*). In *H. rupicola* there is a large frontoparietal fontanel



TEXT FIG. 4*a*, 4*b*. Dorsal and ventral views respectively of the skull of *Lepturichthys nicholsi* Hora; the supracleithrum is shown on one side only.

(fig. 3*c fpf*) and this is the only instance among Homalopteridae where such a fontanel has been noticed by me. An extraordinary development of the frontals is also seen in unrelated forms like *Gyrinocheilus* (Ramaswami, 1952*a*) and *Parapsilorhynchus* and *Psilorhynchus* (Ramaswami, 1952*b*), which are also hillstream or sand-burrowing forms. Flanking the frontals there are the supraorbitals (figs. 1*a*–4*a*, 1*b*–4*b*, 3*c suo*) very poorly developed in *H. amphisquamata* (figs. 3*a*, 3*b suo*). However, in *Gyrinocheilus* (Ramaswami, 1952*a*), the supraorbitals are completely wanting.

Ventrally the orbitosphenoids (figs. 1*b*–4*b os*) and the pleurosphenoids (*pls*) are prominent; the former bone is the larger of the two in all the examples studied except in *H. amphisquamata* (fig. 3*b pls*) where the pleurosphenoid is also well developed. In *H. ocellata* (Sagemehl, 1891) the pleurosphenoid (alisphenoid) is very small. In *Bhavania*, *Balitora*, *H. zollingeri*, *H. leonardi*, *H. rupicola* and

Lepturichthys the optic foramen is situated posteriorly accommodated between the orbitosphenoid (*os*), the pleurosphenoid (*pls*) and the parasphenoid (*pas*). In *H. amphisquamata* the optic foramen (fig. 3*b of*) is situated between the orbitosphenoid (*os*) and the pleurosphenoid (*pls*) and the parasphenoid (*pas*) does not contribute to bounding the foramen. The anterior extension of the parasphenoid (*pas*) in this species is very broad when compared with the other examples studied. In *H. ocellata* (Sagemehl, 1891) the parasphenoid bounds ventrally the optic foramen and is not broad.

In *H. zollingeri* the two orbitosphenoids (fig. 2*b os*) meet mesially and there is a slight projection from the parasphenoid meeting the united orbitosphenoids forming an interorbital septum. In no other Homalopterid do we notice an interorbital septum. Sagemehl (1891) also referred to the complete absence of an interorbital septum in *Homaloptera ocellatea*.

In the Homalopteridae, the parasphenoid (figs. 1*b*–4*b pas*) is broad posteriorly and narrow anteriorly except in *H. amphisquamata* (fig. 3*b pas*) where it is also broad anteriorly.

In each bulbus oculi, there is a pair of large cup-shaped sclerotic bones.

The auditory region.—The auditory region of the Homalopteridae exhibits certain fundamental differences from the same in the Cyprinidae. The auditory capsule is formed by the sphenotic (figs. 1*b*–4*b sph*), the pterotic (*pte*), the epiotic (*epi*) and the prootic (*pro*); roofing this region there are the parietals (*pa*) and forming the floor of the same, the posterior part of the parasphenoid (*pas*) and the basioccipital (*bo*) are seen. There is no frontoparietal fontanel in the examined genera of Homalopteridae except, however, in *H. rupicola*, as noticed in Cobitidae, in *Catostomus* (Catostomidae), in *Cyprinus* and *Amblypharyngichthyes* (Cyprinidae) and *Homaloptera* (Sagemehl, 1891). Nor is there an ethmoid-frontal fontanel in the Homalopteridae as in *Psilorhynchus* (Ramaswami, 1952*b*). In *Bhavania*, *Balitora* (figs. 1*a*, 1*b so*8) and *Homaloptera* (figs. 2*a*, 3*a*, 2*b*, 3*b*, 3*c*) connecting the supraorbital sensory canal (*soc*) with the temporal (*tc*) there is a triradiate canal bone (*sog*, *to*). In *Homaloptera*, connecting the supraorbital (*soc*) and the triradiate sensory canal bones (*to*), there is a small independent canal ossicle (*ios*) sitting on the sphenotic (*sp*) anteriorly, or as in *Balitora* (fig. 1*a*), it may be disposed posteriorly on the sphenotic establishing connexion between the triradiate ossicle and the temporal canal. In *Lepturichthys* (figs. 4*a*, 4*b*) there are two independent ossicles (*ios*, *ios'*) establishing connexion between the supraorbital and temporal canals. In *H. rupicola* and *H. leonardi* the supraorbital limb of the triradiate ossicle (fig. 3*c so*7) reaches the above canal and therefore, there is no independent ossicle as in the other species of *Homaloptera*. It is important to note that the sensory canal does not pass through the sphenotic bone in these examples as it does in the pterotic region.

Posteriorly there are two canal ossicles on the pterotico-epiotic region in all the Homalopterid examples studied except in *H. zollingeri*. One of these is larger (figs. 1*a*, 3*a*, 3*c*, *ste*) and mesial in position connecting the temporal canal with the occipital canal. In my previous paper (Ramaswami, 1948), I had labelled this bone the anterior extrascapular and after examining the Indian Cyprinidae, I find that it should be more correctly called the supratemporal. The lateral ossicle (figs. 1*a*, 1*b*, 3*a*, 3*c* 4*a*, *les*) establishes connexion between the temporal (*tc*) and lateral line canals and this is the extrascapular. Posterior to these two, there is a small bone (*pt*) which sits upon the epiotic (*epi*) and the supracleithrum (*scl*). I had labelled this as the posterior extrascapular and the supracleithrum as the post-temporal in my previous paper (*op. cit.*). They should be correctly called the post-temporal and the supracleithrum respectively. A part of the occipital canal, it is noticed in the Homalopteridae, runs in the parietal bone also.

In *H. zollingeri* the supratemporal appears to be absent and the lateral extrascapular and the post-temporal seem to have fused to form a U-shaped bone (figs.

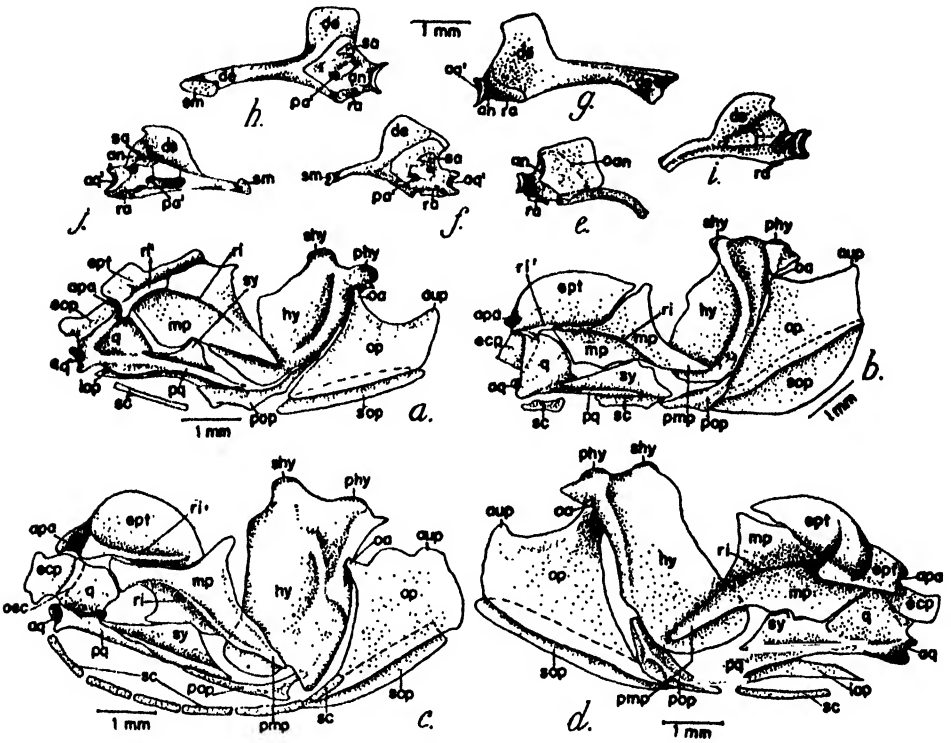
2*a*, 2*b lpt*). This is a peculiar modification of the lateral extrascapular and the post-temporal. Ventrally the subtemporal fossa (figs. 1*b*–4*b stf*) is conspicuously noticed. It may be bounded by the prootic, the pterotic, the epiotic and the exoccipital (*H. zollingeri*, *Lepturichthys*, *Balitora* and *Bhavania*) or it may be seen largely as a depression in the pterotic (*H. rupicola*, *H. amphisqumata*). In all these cases the roof of the subtemporal fossa is formed by the pterotic and epiotic bones. In *H. leonardi* the roofing pterotic wall is thin laterally to the epiotic and moreover, where the temporal canal passes into the supraoccipital one, there is no ossification surrounding the canal so that through these orifices or gaps, one could easily pass a bristle into the subtemporal fossa from the dorsal aspect. From the ventral aspect, these gaps and the temporal and occipital canals can be easily made out through the deep subtemporal fossa. It may not be out of place to mention here that in the Cyprinid examples studied by me, the post-temporal does not convey the sensory canal nor does it show only one articulation with the auditory region in the majority of forms.

The occipital region shows certain interesting features. The supraoccipital (figs. 1*a*–4*a so*) excludes the exoccipital from forming the roof of the foramen magnum. The supraoccipital may project posteriorly in the form of two prominent processes as in *Balitora* (figs. 1*a*, 1*b sup*), *H. leonardi*, *H. amphisquamata* (figs. 3*a*, 3*b sup*) and *Bhavania* or as blunt projections as in *Lepturichthys* (figs. 4*a*, 4*b sup*) or they may be absent as in *H. zollingeri* and *H. rupicola*. The exoccipitals are not visible dorsally except in *H. zollingeri* (fig. 2*a eo*). The lateral fenestra so commonly seen in the exoccipitals of catostomids, cyprinids and cobitids is absent in the Homalopteridae, a fact also recorded by Sagemehl (1891). The basioccipital (figs. 1*b*–4*b bo*) shows a prominent condyle (*con*) which may be projecting as in *H. zollingeri* (fig. 2*b con*) and the pharyngeal processes so commonly met with in the Cyprinidae are absent. However, in *Lepturichthys* (fig. 4*b*), the basioccipital shows a pair of lateral projections (*php*) and the aorta does not run dorsally to these projections. Sagemehl (1891) also noted the absence of the pharyngeal processes in the Homalopteridae.

In a median sectional view of the auditory region of the Homalopteridae, an interesting feature is noticed. While in the cyprinid *Labeo*, a portion of the pterotic is visible in the mesial view, showing the anterior opening of the lateral semicircular canal, in *Bhavania* which I have sagittally bisected and studied, it is kept out. In *Bhavania*, the openings of the anterior semicircular canal are noticed in the sphenotic, those of the lateral and posterior semicircular canals in the sphenotic and epiotic.

The upper jaw.—The upper jaw shows certain features in which it stands apart from the cyprinid one. The operculum (figs. 5*a*–5*d op*) is generally elongated anteroposteriorly and the upper edge of it may show two prominent processes. In describing the catostomid opercular series, Nelson (1949) delineated in the upper border of the operculum a posterodorsal auricular process and an anterodorsal opercular arm and a small articular process just above the articulation with the hyomandibula. In all the Homalopteridae the opercular arm is prominent and while the auricular process is rounded in *H. amphisquamata*, it is more pointed in *H. zollingeri*, *H. rupicola*, *H. leonardi*, *Balitora* and *Lepturichthys*. A lower articular process is not developed in the Homalopteridae. The metapterygoid (*mp*) has a prominent posterior process (*pmp*) which lies laterally to the hyomandibula (*hy*). It shows also a prominent ridge (*ri*). The ectopterygoid (*ecp*) projects in front of the quadrate (*q*) ventrally to the entopterygoid (*ept*). The entopterygoid (*ept*) shows a prominent articular facet for the palatine (*apa*) and in *H. amphisquamata* a prominent ridge (fig. 5*c ri'*) is also seen. In *H. rupicola* and *H. leonardi* the entopterygoid is bent at right angle laterally from the ridge. The symplectic (figs. 5*a*–5*d sy*) is large and I labelled this bone the 'posterior ectopterygoid' in my previous paper (Ramaswami, 1948). At the time I argued that in *Bhavania* the

bone which I labelled symplectic showed no sensory canal in it and therefore, it could not be a preopercular and I accordingly called it the symplectic. Having studied a large number of forms, I hasten to correct the nomenclature previously employed and the bones labelled symplectic and posterior ectopterygoid in *Bhavania Balitora* and *Gastromyzon* (Ramaswami, 1948) must now be read as preopercular and symplectic respectively. There is a set of two independent sensory canal ossicles (fig. 5*b sc*) in front of the preopercular (*pop*) in *H. zollingeri*, *H. rupicola* and *H. leonardi* or a set of six sensory canal ossicles (fig. 5*c sc*) ventrally to the preopercular (*pop*), the first one being disposed on the lower portion of the hyomandibula as in *H. amphisquamata*. While in *H. zollingeri* and *H. rupicola* the



TEXT FIG. 5*a*. Lateral aspect of the upper jaw of *Balitora brucei* var. *mysorensis* Hora.
,, 5*b*. Lateral aspect of the upper jaw of *H. zollingeri* Bleeker.
,, 5*c*. Lateral aspect of the upper jaw of *H. amphisquamata* W. & de B.
,, 5*d*. Lateral aspect of the upper jaw of *Lepturichthys nicholsi* Hora.
,, 5*e*, 5*f*. Lateral and mesial aspects respectively of the lower jaw of *H. zollingeri* Bleeker.
,, 5*g*, 5*h*. Lateral and mesial aspects respectively of the lower jaw of *H. amphisquamata* W. & de B.
,, 5*i*, 5*j*. Lateral and mesial aspects respectively of the lower jaw of *Lepturichthys nicholsi* Hora.

preopercular carries the sensory canal in it, in *H. amphisquamata* the preopercular is free of it and the chain of six ossicles referred to above carries it into the lower jaw. In *Balitora* and *Lepturichthys* the preopercular (figs. 5*a*, 5*d pop*) has a large sensory canal ossicle (*sc*) in front of it. The posterior process of the quadrate (*pq*) is very large in these two genera while in *Homaloptera* (figs. 5*b*, 5*c pq*), it is comparatively smaller.

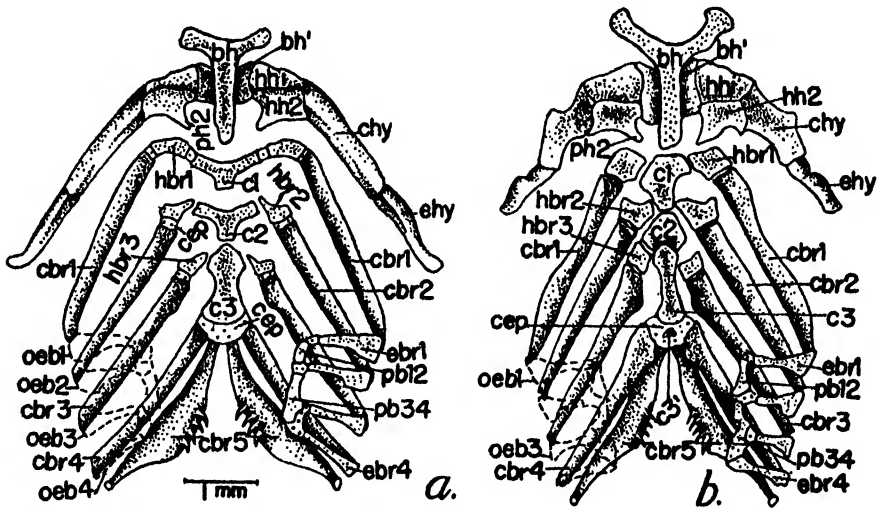
The palatine has already been described.

The lower jaw.—Each ramus of the lower jaw shows the four bones, viz., the angular (figs. 5*e*–5*j an*), the retroarticular (*ra*), the dentary (*de*) and the mesial one

(figs. 5*f*, 5*h*) or two (fig. 5*j*) sesamoid angulars (*sa*). Peculiarly, there is a passage (figs. 5*f*, 5*h*, 5*j pa'*) in the angular (*an*) covering Meckel's cartilage. I have already described this passage as a sensory canal in *Bhavania* and *Balitora* (Ramaswami, 1948).

The hyobranchial apparatus.—Certain interesting features are noticed in the hyobranchial apparatus of the Homalopteridae. In the hyoid cornu there is a median bony piece (figs. 6*a*, 6*b bh'*) connecting the two cornua and dorsally to this, there is a Y-shaped basihyal (*bh*). Probably the ventral piece is also a part of the basihyal. There are two pairs of hypohyals (*hh*1, *hh*2) and the posterior one in each shows a spinous projection posteriorly. There are three pairs of hypobranchs (*hbr*1, *hbr*2, *hbr*3) as in the Cyprinidae and three copulae (*c*1, *c*2, *c*3); the first two copulae are cruciform in *Homaloptera* and *Balitora* while in *Bhavania* and *Lepturichthys* (fig. 6*b* *c*1, *c*2) they are irregular in outline. The original cartilaginous reminiscences (*cep*) have been drawn in the figures wherever they were seen clearly.

There are two pairs of pharyngobranchs (figs. 6*a*, 6*b* *ph*12, *ph*34) connected together by cartilaginous epiphyses. These pharyngobranchs probably represent



TEXT FIG. 6*a*. The hyobranchial apparatus of *H. amphisquamata* W. & de B.
,, 6*b*. The hyobranchial apparatus of *Lepturichthys nicholsi* Hora.

the united first and second, and the third and fourth pharyngobranchs respectively. The fifth ceratobranch (*cbr*5) carries teeth which are regularly arranged.

The parahyoid is winglike and is attached anteriorly to the hypohyals by a pair of strong ligaments and the bone is thin and long posteriorly.

The Weberian Ossicles.—The gasbladder in the Homalopteridae is completely divided into two, and the two parts are, however, connected by a commissure posteriorly. The divided gasbladder and the posterior commissure are all encased in bone. In the structure and disposition of the gasbladder and the associated Weberian ossicles, the Homalopteridae resemble the Nemachilini (Cobitidae).

Projecting posteriorly from the commissural portion in *H. leonardi*,* there is a long posterior portion of the gasbladder reminiscent of the condition seen in the Cyprinidae or that in the cobitid *Nemachilus* (Chranilov, 1927). In *H. zollingeri* also there is a posterior bag which, however, is small (fig. 7*f pgb*) and oval in outline. In other species of *Homaloptera* as also in the other genera of the family examined by me, this posterior portion of the gasbladder is absent. Sagemehl (1891) did

* I have examined only one specimen and I do not know if this is an individual variation.

not refer to a posterior sac in *H. ocellata* and obviously it must have been absent in it.

In the Nemachilini (Cobitidae) according to Chranilov (1927) the first four vertebrae take part in the formation of the capsule and the Weberian ossicles. The ribs and transverse processes of the second vertebra form the anterior wall of the capsule; the remaining covering of the capsule is derived from the ossa and the transverse processes of the fourth vertebra. Laterally there is a big gap in the wall of the capsule where the gasbladder can be seen projecting. In the Cyprinidae there is generally an os suspensorium developed from the mesial aspect of the pleural ribs of the fourth vertebra. In the Nemachilini, on the other hand, the medial and lower wall of the capsule and also the wall of the transverse canal are formed by the ossa suspensoria (Chranilov, 1927). Dorsally the intercalarium and the V-shaped tripus are enclosed in the paravertebral space by the extension of the pedicel of the united second and third vertebrae. On the ventral aspect, there is a mesial depression in which the centrum of the united second and third vertebrae, that of the fourth vertebra, the transverse canal and a pair of anterior orifices through which the articulation of the mesial limb of the tripus with the united centrum of the second and third vertebrae is seen, are visible.

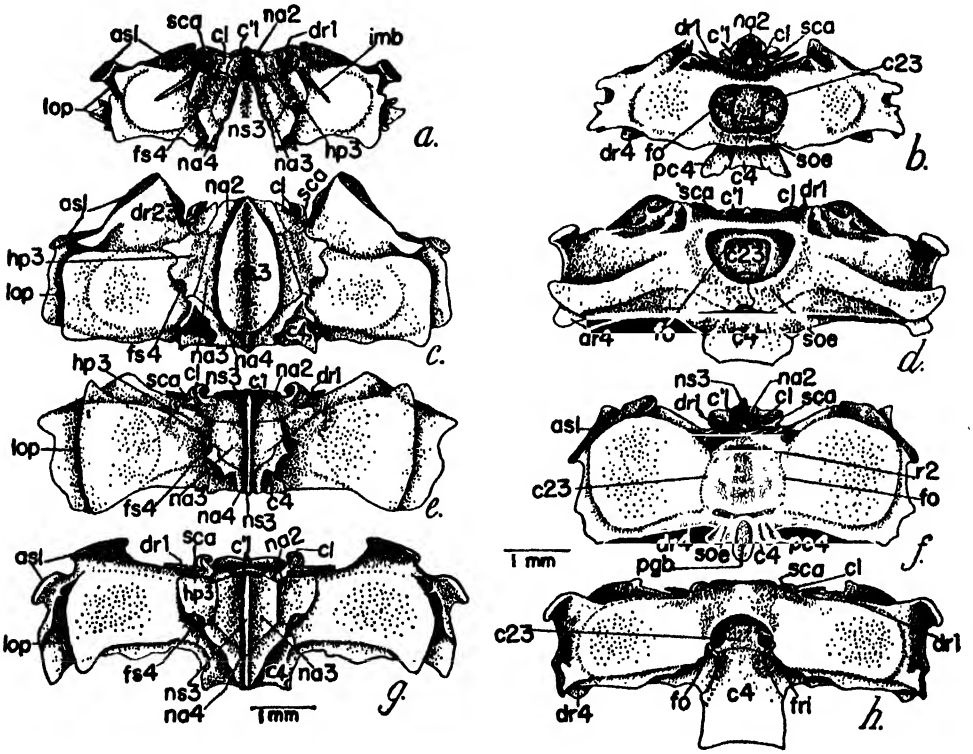
Watson (1939) who studied the development of the Weberian ossicles in the goldfish differed from the observations of the previous workers and I have also followed the nomenclature employed by Watson in my previous papers. He, however, did not study the development of a nemachiline or a homalopterid gasbladder where the latter possesses a capsule derived from vertebral parts. Nor have I been able to study the development of the capsule or ossicles but I am following the description of Chranilov (1927) with regard to the capsule and that of Watson with regard to the origin of the ossicles.

If Chranilov's (1927) description of the gasbladder and the Weberian ossicles is also applicable to the Homalopteridae, then in this family as in the Nemachilini, the first four vertebrae take part in the formation of the bony capsule and also the Weberian ossicles. The anterior part of the capsule is partly formed by the dorsal ribs* (the transverse processes of Chranilov) of the second vertebra and in front of this, the small centrum (figs. 7*a*, 7*b*, 7*d*–7*g c'*1) of the first vertebra with a pair of dorsal ribs (*dr*1) is seen. It is difficult to demarcate the contribution of the second pleural ribs towards capsule formation in the adult. In a form like *Psilorhynchus* (Ramaswami, 1952*b*) where the gasbladder is encased only anteriorly, I have pointed out that the capsule is probably derived from the dorsal ribs of the second vertebra. It is very likely that the large articulating processes in *Lepturichthys* (fig. 7*c asl*) forming the anterior wall of the gasbladder is also formed by the dorsal ribs of the second vertebra, probably with a contribution from the third (*dr*23). In the Homalopteridae, the second vertebral neural arch arising probably independently of the basidorsals, shows on either side the claustrum (figs. 7*a*, 7*c*, 7*e*, 7*g cl*); this arch does not show a neural spine in the genera examined by me and in *Lepturichthys* and *H. zollingeri*, the neural spine of the third vertebra projects anteriorly over this. The third pedicel shows a dorsolateral extension (*hp*3)† which covers the paravertebral space and also a prominent neural arch (*na*3), which like the second has arisen

* Watson (1939) described that the so-called 'transverse processes' were really in the nature of dorsal ribs of the piscine vertebra. The referee kindly pointed out to me that the 'transverse processes', in the Cyprinids at any rate, are the *pleural* ribs. Not having examined embryonic stages of the fish studied by me, I am unable to comment on this.

† On a comparison of the third vertebral elements of the Cyprinidae and Homalopteridae, it is noticed that the structure which I have called a dorsolateral extension of the third pedicel in the Homalopteridae has been labelled the neural arch in Cyprinidae by Chranilov (1927, fig. 4) and Berg (1940, fig. 154); the one I have labelled neural arch is considered by them as neural spine. Peculiarly the socalled third neural arch is not in line with those of second and fourth vertebrae. However, a study of the development of the anterior vertebrae would throw a lot of light on this.

probably independently. The third neural spine may be high and elevated as in *Homaloptera* or become broadened out as in *Balitora* and *Lepturichthys*. Posterior to the lateral extension of the third pedicel, there is an orifice for the fourth spinal nerve (*fs*4). The united centrum of the second and the third vertebrae (figs. 7*b*, 7*d*, 7*f*, 7*h* *c*23) is visible on the ventral aspect. In *H. zollingeri* on the ventral aspect, between the capsules and the united centrum, a ridge (fig. 7*f* *r*2) is noticed probably contributed by the dorsal ribs of the second vertebra, dorsally to which there is a passage; this is not noticed in the other examples studied by me. Further, the posterior transverse bony canal in which the commissural portion of the gasbladder lies, may be small (figs. 7*b*, 7*f* *soe*) or broad (fig. 7*d* *soe*) representing probably the united ossa suspensoria and the esophageal processes. It is important to note



TEXT FIG. 7*a*, 7*b*. Dorsal and ventral views respectively of the gasbladder capsule and the Weberian ossicles of *Balitora brucei* var. *mysorensis* Hora.

„ 7*c*, 7*d*. Dorsal and ventral views respectively of the gasbladder capsule and the Weberian ossicles of *Lepturichthys nicholsi* Hora.

„ 7*e*, 7*f*. Dorsal and ventral views respectively of the gasbladder capsule and the Weberian ossicles of *H. zollingeri* Bleeker.

„ 7*g*, 7*h*. Dorsal and ventral views respectively of the gasbladder capsule and the Weberian ossicles of *H. amphisquamata* W. & de B.

that the neural arches of the second and third vertebrae are separate as in *Labeo* (Sarbahi, 1932), Catostomidae (Nelson, 1948) and *Gyrinocheilus* (Ramaswami, 1952*a*). The fourth pedicel in the Homalopteridae also shows a neural arch (figs. 7*a*, 7*c*, 7*e*, 7*g* *na*4) which may project as a neural spine (*Lepturichthys*, *H. amphisquamata*) or as in *Balitora*, may be covered over by the flattened spine of the third vertebra. The centrum of the fourth vertebra (figs. 7*b*–7*h* *c*4) is large and usually shows lateral winglike extensions (*pc*4). The remaining posterior part of the bony capsule of the gasbladder is formed by the dorsal ribs (*dr*4) and ossa suspensoria of the fourth vertebra.

The Weberian ossicles are also based on the nemachiline plan. The claustrum (figs. 7*a*, 7*c*, 7*e*, 7*g cl*) probably arising independently in the region of the first vertebra, articulates laterally with the reduced neural arch of the second vertebra. It shows a flat piece (corpus claustri) with which it comes in contact with the second neural arch and a cuplike (scutulum claustri) ventral portion which closes a similar cup of the scaphium enclosing the atrium sinus imparis.

The second of the series of the Weberian ossicles is the scaphium (figs. 7*a*, 7*c*, 7*e*, 7*g sca*). This is a modification of the basidorsal of the first vertebra according to Watson (1939) in the goldfish, and in the Homalopteridae, the scaphium is in the form of a funnel whose spout is short and solid. The funnel,—the concha stapedis, forms with the scutulum claustri a case for the atrium sinus imparis. Like that of *Nemachilus* (Chranilov, 1927), the scaphium shows only the processus articularis stapedis and also a region where the interosseous ligament (ligamentum incudo stapedium) is inserted. An orifice for the first spinal nerve seen in some cyprinids and the processus ascendens stapedis are not present in the homalopterid scaphium.

The intercalarium is a small ossification (sesamoid) in the ligament connecting the scaphium and the tripus. Following Watson (1939), it also probably arises in the Homalopteridae in the interosseous ligament. In the goldfish, according to Watson, the basidorsal of the second vertebra contributes that part of the ossicle which articulates with the second centrum. This latter part is absent in the Homalopteridae unlike the Psilorhynchidae (Ramaswami, 1952*b*) and the Cyprinidae.

The tripus is the last of the series and is derived from the basiventral of the third vertebra with the addition of a mesenchymatous mass according to Watson (1939). Whether the tripus arises similarly in the Homalopteridae, I am at present unable to say. The large tripus with the characteristic three processes seen in the Cyprinidae is reduced in the Homalopteridae as in Nemachilini. In the Homalopteridae, the posterior process is short and laterally disposed coming in contact with the gasbladder. The anterior and the articular processes of the tripus are cylindrical and the latter process comes in contact with the centrum of the third vertebra.

Having studied the Weberian apparatus in the Gyrinocheilidae and Psilorhynchidae, I am able to compare the apparatus in these three families. In *Gyrinocheilus* the triangular tripus is partially covered over by the horizontal extension of the third pedicel, the neural arches of the second and third vertebrae are independent and the pleural ribs of the second and fourth vertebrae are united, thus resembling the condition in the Catostomidae (Nelson, 1948); in the disposition of the other structures of the apparatus, *Gyrinocheilus* resembles the Cyprinidae. In *Psilorhynchus* (Ramaswami, 1952*b*), the gasbladder is incompletely divided and each part is covered partially anteriorly by a capsule formed by the dorsal ribs (transverse processes of most previous authors) of the second vertebra and this condition may be considered as the first step towards the modification of the bladder and its capsule noticed in the Homalopteridae. The tripus in *Psilorhynchus* (Ramaswami, 1952*b*), is still triangular and has not become triradiate as in the Nemachilini and Homalopteridae but is partially covered by the capsule.

The basipterygium.—Fang (1930) utilised the nature of the basipterygium in separating the 'Homalopterini' from 'Gastromyzonini'; according to him, the basipterygium of the Homalopteridae possesses a lateral foramen and dorsally at the region of the foramen, a modified rib gains attachment by means of a ligament. In *Balitora*, *Lepturichthys* and *Homaloptera* the basipterygium shows the lateral orifice but in *H. zollingeri* instead of a large orifice, there are two small foramina; in *Lepturichthys* and *H. amphisquamata* there is in addition a large anterior foramen also. The usefulness of this character can only be judged after examining a few more genera of Homalopteridae.

In the arrangement of the caudal fin skeleton of the Homalopteridae, the number of hypurals attached to the last vertebra varies. Ventrally to the urostyle

there may be six (*Balitora*, *H. amphisquamata*), seven (*H. zollingeri*, *H. rupicola*) or eight (*H. leonardi*) hypurals. I was not able to study the caudal fin of *Lepturichthys* as it was damaged.

Discussion.

It was pointed out by Hora (1932) that among the Homalopteridae, the genus *Homaloptera* was very generalised and it formed the starting point for the evolution of the other genera of Homalopteridae.

In the structural organization of the skull, the four species of *Homaloptera* examined by me, viz., *rupicola*, *leonardi*, *zollingeri* and the much flattened *amphisquamata* show so much of difference that to start with a genus like *Homaloptera* to study the evolution of other homalopterid forms, it becomes extremely difficult. After studying the scale structure of homalopterid fishes, Law (1950) stated that 'the genus *Homaloptera* as constituted at present is probably a heterogeneous assemblage of forms'.

H. amphisquamata stands apart from the other Homalopteridae and also from its relatives like *zollingeri*, *rupicola* and *leonardi*. At least nine important features could be recounted in which *amphisquamata* differs from the other species. They are:

(1) the prevomer is short and broad,
(2) the lacrimojugal is not associated closely with the sensory canal bones,
(3) the lateral ethmoid processes are short and blunt,
(4) the median articulation of the palatine is only with the elongated second preethmoid,
(5) the median rostral has two lateral projections for the maxillary ligaments,
(6) the anterior part of the parasphenoid is very broad,
(7) the optic foramen is between the orbitosphenoid and pleurosphenoid,
(8) the subtemporal fossa is a depression in the pterotic only, a feature which it shares with *rupicola*,
(9) the prepalatine articular facet of the palatine is long,
(10) the palatine does not show a lacrimojugal facet, a feature also shared by *rupicola*.

In the ethmoid region, the broad supraethmoid portion of the ethmoid is firmly articulated with the frontals, a feature also noticed in the Cyprinidae. In *H. zollingeri* there is a peculiar depression in the anterior end of the supraethmoid whose significance, it is difficult to understand. In *H. rupicola*, a frontoparietal fontanel is noticed. In *Psilorhynchus** (Ramaswami, 1952*b*), a similar fontanel is noticed in between the supraethmoid and the frontals; in the Cobitidae and a few genera of Gastromyzonidae (*Vanmanenia*, *Crossostoma*, *Glaniopsis*) there is a frontoparietal fontanel. Though Sagemehl (1891) considered the occurrence of the frontoparietal fontanel as without any significance, the hillstream and the sand-burrowing forms and other loaches may be having them for serving some physiological purpose.

The median process of the supraethmoid is excessively long in *H. amphisquamata*; in *Psilorhynchus* (Ramaswami, 1952*b*) a similar elongated process is noticed.

The maxilla of the Homalopteridae shows a very prominent dorsal premaxillary process; the rostral process of the maxilla almost stretches at right angle to the dorsal process and therefore, the fork in which the premaxilla is held is very wide.

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* In the *Psilorhynchus* specimens sent to me from Lucknow by Dr. B. S. Kaushiva, I notice *two* fontanels; one between the supraethmoid and the frontals and the other between the frontals, parietals and supraoccipital which latter, I have called the frontoparietal fontanel.

The rostral process of the premaxilla is very long in *H. amphisquamata*, *Balitora* and *Lepturichthys* while in *H. zollingeri*, it is very short. In all the genera the tips of the rostral processes come in contact with the median rostral or extend slightly beyond but in *H. rupicola*, the tips rest on the supraethmoid.

The prepalatine and the first preethmoid are prominent bones; in *H. zollingeri* and *Balitora* the prepalatine is short. The prepalatine may articulate directly with a facet on the posterior face of the maxilla laterally to the articulation with the first preethmoid as in *Homaloptera* and *Lepturichthys* while in *Balitora* there is a small sesamoid bone intercalated in between. It was pointed out that in order to promote greater movability of the ethmoid region, these hillstream forms developed a second preethmoid with which anteriorly the first preethmoid articulated and laterally, the palatine; in *H. amphisquamata* the second preethmoid is so large that the palatine does not articulate with the ethmoid at all. In *H. rupicola* the lacrimojugal process of the palatine comes in contact with the lacrimojugal and at this region the prepalatine articulates; there is no separate articular facet for it.

In the Homalopteridae there is a large lacrimojugal with the sensory canal excluded from it; Hora (1932) called it a preorbital bone. It is difficult to say if this composite bone is really formed by the fusion of a lacrimal and a jugal since in those fossil forms where a lacrimojugal is described (Moy-Thomas, 1937), it always leads the suborbital sensory canal. While in the cyprinid examples and in several other genera also, the short lacrimal is the anteriormost of the suborbital series of bones, always canaliculated and leading the suborbital sensory canal, in the Homalopteridae the sensory canal ossicles are independent and they may be closely associated with the lacrimojugal as in *Balitora brucei* and *H. zollingeri* or may lie separately. Moreover, the size of the lacrimojugal in the Homalopteridae is larger than that in the other subfamilies and therefore, I propose to call it a lacrimojugal as I have already done in my previous paper (Ramaswami, 1948) for describing the bone following Moy-Thomas (1937). At any rate, associated with this enlarged lacrimojugal, as already said, there are sensory canal ossicles. In *H. zollingeri*, *H. rupicola* and *H. leonardi* three ossicles are noticeable ventrally to the lacrimojugal while in *amphisquamata*, there are a few by the side of the lacrimojugal and an enlarged one extending in front of it. In *Balitora* there is one in front of the lacrimojugal associated with a triradiate ossicle. Probably the bony ossicle in front of the lacrimojugal or just below anteriorly to it represents a rostral (Moy-Thomas, 1937). Sometimes when the lacrimal itself accommodates the sensory canal in it as in *Psilorhynchus* (Ramaswami, 1952*b*), it may be possible to call the large one posterior to it a jugal, but in the Homalopteridae, where the sensory canal ossicles are independent of the 'lacrimal', nomenclature of the former becomes difficult. I have therefore, cautiously labelled the suborbital ossicles by the ordinals 1, 2, 3 etc.

The prevomer may be narrow with a fairly long posterior process as in *H. zollingeri*, *H. rupicola*, *H. leonardi*, *B. brucei*, *B. brucei* var. *mysorensis*, and *Lepturichthys* while in *H. amphisquamata* the prevomer is broad with a short posterior process. In *Balitora* only, on the dorsal aspect, an anterior extension of the prevomer is noticed while in all other genera the prevomer does not extend anteriorly. In *Gyrinocheilus* (Ramaswami, 1952*a*), the prevomer anteriorly gives rise to two prominent processes with an indentation in between while the posterior short blunt process is like that in *H. amphisquamata*. In *Psilorhynchus* (Ramaswami, 1952*b*), the bone extends in front and posteriorly shows a long slender process; in *Parapsilorhynchus* (Ramaswami, 1952*b*) the bone is broad as in *H. amphisquamata* and shows only a short process. A similar short posterior process has been observed by me in a large number of cyprinids studied by me.

The lateral ethmoid shows a longish lacrimojugal process in *Balitora*, *Bhavania* and *Lepturichthys* and a similar shorter process posteriorly. The anterior process

obviously supports the lacrimojugal. In *Homaloptera* peculiarly the lateral processes are short resembling those in *Psilorhynchus* and *Parapsilorhynchus* (Ramaswami, 1952*b*) and the other cyprinids studied by me. In *Gyrinocheilus* (Ramaswami, 1952*a*) the processes are fairly well developed.

In the orbitotemporal region the frontals are generally broad and on either side may show the supraorbital as in *Balitora*, *Lepturichthys*, *H. zollingeri*, *H. rupicola* while in *H. amphisquamata* the supraorbitals are poorly developed. In *Psilorhynchus* (Ramaswami, 1952*b*) the supraorbitals are absent.

Ventrally there is an exceedingly interesting peculiarity in the orbitotemporal region. In *Balitora*, *Lepturichthys* and *H. zollingeri* the orbitosphenoid is fairly large and between it and the small posterior pleurosphenoid and the parasphenoid, the optic foramen is noticed; in *H. amphisquamata* the orbito- and pleuro-sphenoids are small and they include in between them the optic foramen, the parasphenoid being kept out. In *Gyrinocheilus* (Ramaswami, 1952*a*) it was noticed that the lateral ethmoid also extended posteriorly to bound the optic foramen; in *Psilorhynchus* and *Parapsilorhynchus* (Ramaswami, 1952*b*) the orbitosphenoid, pleurosphenoid and parasphenoid bound the optic foramen.

In the auditory region, the homalopterid skull shows certain peculiarities. In *Balitora* and *Lepturichthys* the dorsal aspect of the skull discloses a large part of the sphenotic and a triradiate sensory canal bone connects the supraorbital and posteriorly the temporal canal as in *Balitora*, or as in *Lepturichthys* there are two independent ossicles connecting the canals; there is also an independent sensory canal ossicle sitting on the sphenotic posteriorly in *Balitora*. In *H. amphisquamata* and *H. zollingeri* the triradiate ossicle establishes connexion with the supraorbital by means of an independent ossicle sitting on the sphenotic; in *H. rupicola* an independent ossicle is absent.

In *Balitora*, *Lepturichthys* and *H. amphisquamata* connecting the temporal canal with the supraoccipital there are two sensory canal ossicles, and connecting the former with the lateral line canal, there is an ossicle. In my previous paper (Ramaswami, 1948) I described these three ossicles as anterior, posterior and lateral extrascapulars. The large mesial one corresponds with the supratemporal of the cyprinids which nomenclature I am now using; the posterior one is the posttemporal which connects the supracleithrum with the skull and the lateral one is the lateral extrascapular leading the temporal canal to the lateral line. In the Cyprinidae, the posttemporal is generally connected to the epiotic and the pterotic regions of the skull by two processes of the posttemporal.

In *H. zollingeri* the supratemporal is absent and the lateral extrascapular and the posttemporal appear to be united into a single U-shaped canal ossicle whose lateral limb connects the lateral line canal while the mesial limb sits on the epiotic.

There is a well formed subtemporal fossa on the ventral aspect seen accommodated between the exoccipital, the prootic and the pterotic in *Balitora*, *Lepturichthys* and *H. zollingeri*; the epiotic also forms the roof of it. However, in *H. amphisquamata* the subtemporal fossa is seen as a depression in the pterotic, bone only. In *Gyrinocheilus* (Ramaswami, 1952*a*) there is a shallow subtemporal fossa; laterally there is also a lateral temporal fossa so far noticed only in this example and the Cobitidae by me. In *Psilorhynchus* (Ramaswami, 1952*b*) also there is a shallow subtemporal fossa.

In the Cyprinidae and the Psilorhynchidae the basioccipital shows a prominent pharyngeal process ventrally to the condyle through which the dorsal aorta passes and the process is covered by a large horny pad; in Gyrinocheilidae, from the posterior portion of the basioccipital, two processes are present which however, do not completely enclose the aorta. In the Homalopteridae blunt projections are noticed from the posterior portion of the basioccipital in *Balitora* and *Lepturichthys*; in *Homaloptera* even these blunt processes are wanting; the absence of the horny pad has already been recorded by Regan (1911).

In the upper jaw the opercular shows prominently the opercular arm and the auricular processes; the sensory canal noticed in the opercular of some Cyprinidae is absent in the Homalopteridae. In the hyobranchial apparatus the basihyal consists of two parts: a dorsal Y-shaped portion resting on a rectangular one. There are uniformly three copulae, three hypobranchs and two pharyngobranchs as in the Cyprinidae. The lower jaw shows peculiarly one or two sesamoid angulars on the mesial aspect which are also seen in the nemachiline genera examined by me. In *Gyrinocheilus* (Ramaswami, 1952*a*) there are three pharyngobranchs and in *Psilorhynchus* (Ramaswami, 1952*b*) there are only two.

The palatine normally articulates ventrally with the second preethmoid and dorsally the ethmopalatine projection is connected with the median process of the ethmoid by a ligament. Anterolaterally *Balitora*, *Lepturichthys* and *H. zollingeri* show a prominent process towards the lacrimojugal. Posteriorly the entopterygoid articulates with the palatine.

The Weberian apparatus of the Homalopteridae resembles that seen in the Nemachilini and to a limited extent the Psilorhynchidae. The tripus in the Homalopteridae is modified into a Y-shaped structure with one of the shorter limbs of the Y in contact with the ligament and the other articulating with the fused third vertebral centrum. The dorsal ribs of the second and fourth vertebrae are so modified as to form a capsule for the divided gasbladder, the two parts of the latter being connected by a commissure. Possibly the pleural ribs (ossa suspensoria) of the fourth vertebra also take part in the formation of the capsule wall ventrally as in the Nemachilini (Chranilov, 1927). With regard to the large supracleithral articular facet of the gasbladder capsule in *Lepturichthys*, I have hazarded that it may have been formed by the dorsal ribs of the second and *third* vertebrae, though the third vertebra is usually described as having no parapophyses or ribs. In the Cyprinidae the Weberian ossicles are not enclosed by the extensions of the neural arches.

The Homalopteridae are characterised as fishes possessing no posterior portion of the gasbladder. However, I have noticed the occurrence of a short posterior one in *H. zollingeri* and a long one in *H. leonardi*. In a few Gastromyzonid examples like *Beaufortia*, *Protomyzon* and *Crossostoma*, I have also noticed the occurrence of a small posterior portion of the gasbladder.

A comparative study of the skull structure of the Homalopterid genera discloses certain interesting points about their relationships. The Homalopteridae show a number of Cyprinid features which are as follows:

(1) the firmly articulated supraethmoid and frontals,
(2) the maxillae and the premaxillae show the characteristic cyprinid features, *viz.*, the dorsal premaxillary process of maxilla, the ventral rostral process, and the rostral process of the premaxilla,
(3) the palatine articulates with the ethmoid and the preethmoid,
(4) the orbitosphenoid, the pleurosphenoid and the parasphenoid enclose the optic foramen generally,
(5) the occurrence of only four otic bones, *viz.*, the prootic, the pterotic, the sphenotic, and the epiotic and the absence of the opisthotic,
(6) the prootic, the pterotic and the exoccipital accommodate the subtemporal fossa generally,
(7) the occurrence of three copulae, three hypobranchs and two pharyngobranchs.

The Homalopteridae (*sen. stric.*) having taken their origin from an ancestral cyprinid stock evolved in a different environment altogether; the genera adapted themselves to fast running brooks and as a result, exhibit certain characteristic features :

(1) Like the head of loaches living in crevices, etc., the ethmoid region of the Homalopteridae also developed the preethmoids and the prepalatines to obtain greater freedom of movement of the snout but the ethmoid remained unaffected,
(2) The lacrimal, bereft of the sensory canal, increased in size probably uniting with a posterior jugal (also without a sensory canal in it) to support the snout as a lacrimojugal and with a rostral in front,
(3) The lateral ethmoid developed laterally anterior and posterior processes, the former supporting the lacrimojugal,
(4) The firm articulation of the supracleithrum with the side of the gasbladder capsule has already been noted by previous workers (Hora, 1932).

Associated with the characters enumerated above, there are others which distinguish the Homalopteridae from the Cyprinidae: they are,

(1) In the upper jaw, the opercular is elongated in the linear axis of the animal, the preopercular is reduced in size and the posterior process of the quadrate is large. In addition, generally a set of sensory canal ossicles is noticed leading to the mandible.
(2) In the lower jaw, the sensory canal (?) is peculiarly noticed on the mesial side in the angular and not on the lateral side as in the Cyprinidae.
(3) The divided gasbladder is enclosed in a capsule which is formed by the dorsal ribs of the second and fourth vertebrae; probably the pleural ribs also take part in it. The tripus is completely modified in its shape; it is Y-shaped with one of its anterior limbs short which is connected with the interosseous ligament. The other limb articulates with the centrum of the fused third vertebra and the short posterior portion of the Y-shaped tripus comes in contact with the gasbladder.
(4) The basipterygium differs in its shape from that in the Cyprinidae. The occurrence of a lateral foramen in the basipterygium which is considered as a diagnostic feature of the Homalopteridae by Fang is also noticed by me; in *H. zollingeri*, however, there are two small foramina instead of a large one.

Sagemehl (1891) who studied the cyprinid skull in great detail pointed out that in the possession of the subtemporal fossa and the 'labyrinthnische', *Homaloptera*, the only genus which he studied, resembled Barbidae and at the same time pointed out also its cobitid affinities in possessing six barbels, in the bones of the upper jaw, of the preopercular, and of the gasbladder. Berg (1947) as already pointed out, included the Homalopteridae comprising the Homalopterini and Gastromyzonini under the suborder Cyprinoidei (Eventognathi).

I have studied a number of genera of Cobitidae and I do agree with Sagemehl that the Homalopteridae resemble the Cobitidae, if by Cobitidae he meant the nemachiline subdivision. This affinity according to me is purely due to convergence and is of little phylogenetic significance. For, if we assume that nemachiline ancestors gave rise to the homalopterid forms, it becomes difficult to explain how the slender supraethmoid part of the ethmoid of the former could have become so broad in the Homalopteridae where the said bone is uniformly broad as in the Cyprinidae; how the very shallow subtemporal fossa of the Nemachilini could have given rise to the deep subtemporal fossa of the Homalopteridae like that of the Cyprinidae; how the supraorbital which is absent in the Cobitidae could have reappeared in the Homalopteridae as noticed in the cyprinids. While there are four copulae in the Nemachilini, there are only three in the Homalopteridae and Cyprinidae. Therefore, I propose to derive the Homalopteridae from a remote

cyprinid ancestor, and the cobitids which also took their origin from a similar cobitid ancestor moved on parallelly with the Homalopteridae.

It has not been possible for me to find out any cyprinid genus which may have given rise to the Homalopteridae. But a study of the cyprinid, cobitid and homalopterid skull leaves no doubt that the Homalopteridae evolved from a remote cyprinid-like ancestor and moved parallelly with the cobitids. It may not be out of place to point out here that the Psilorhynchidae also appear to be evolving to show homalopterid affinities. That the Gastromyzonidae show a number of features in which they resemble the Homalopteridae is undoubted but the former seem to have taken their origin separately altogether and therefore, there is ample justification for raising the two subfamilies Homalopterini and Gastromyzonini to the rank of families.

Summary.

1. The four species of *Homaloptera* examined show great structural variations that it is not possible to trace the evolution of the Homalopteridae starting from a genus like *Homaloptera*.

2. Laterally to the ethmoid and prevomer, a second preethmoid is developed in the Homalopteridae and the elongated first preethmoid articulates with this. The development of this bone is probably to give greater mobility to the jaws.

3. The Homalopteridae show a prominent lacrimojugal and this enlargement is obviously an adaptation to torrential life.

4. The subtemporal fossa is large and is accommodated by the exoccipital, prootic and pterotic; the epiotic also roofs it. In *H. amphisquamata* the fossa is noticed only in the pterotic.

5. The typical pharyngeal processes through which the dorsal aorta passes are not noticed in the Homalopteridae.

6. The Weberian apparatus and the gasbladder resemble the Nemachiline ones. The dorsal ribs of the second and fourth vertebrae mostly form the gasbladder capsule and the two halves are connected by a posterior commissure; it is difficult to make out the contribution of the pleural ribs towards capsule formation. Peculiarly a posterior portion of the gasbladder is also seen in *H. leonardi* and *H. zollingeri*.

7. The Homalopteridae resemble the Cyprinidae in many features but differ from them in possessing an elongated opercular bone, mesial sensory canal in the lower jaw, the laterally divided gasbladder enclosed in bone and in the structure of the basipterygoids.

8. It is argued that the Homalopteridae took their origin from a cyprinid-like ancestral stock and evolved parallelly with the Cyprinidae; the Cobitidae which arose from a Cobitid stock also show many similarities.

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Lettering.

an .. angular;
apa .. facet of the entopterygoid for articulation with palatine;
apv .. anterior projection of prevomer;
aq .. articular facet of quadrate with lower jaw;
aq' .. articular facet of the lower jaw with quadrate;
asl .. articular facet of the capsule with the supracleithrum;
aup .. auricular process;
bh .. basihyal;
bh' .. ventral piece of basihyal;
bo .. basioccipital;
*c*1–*c*3 .. copulae 1, 2, 3;
*c*3 .. ossification posterior to copula 3;
*c'*1 .. / *c'*4 .. centrum of vertebra 1 and 4;
*c*23 .. united centrum of vertebrae 2 and 3;
*cbr*1 .. / *cbr*2 .. / *cbr*3 .. / *cbr*4 .. / *cbr*5 .. ceratobranchials 1–5;
cep .. cartilaginous epiphysis;
chy .. ceratohyal;
cl .. claustrum;
con .. condyle;
de .. dentary;
dpm .. dorsal premaxillary process of maxilla;
*dr*1 .. / *dr*4 .. dorsal rib of vertebrae 1 and 4;
*dr*23 .. united dorsal ribs of vertebrae 2 and 3 (?);
*ebr*1 .. / *ebr*4 .. epibranchial 1 and 4;
ecp .. ectopterygoid;
ehy .. epihyal;

eo .. exoccipital;
enp .. articular facet of palatine with entopterygoid;
epi .. epiotic;
epp .. ethmoid process of palatine;
ept .. entopterygoid;
et .. ethmoid;
fac .. an articular facet on the ventral aspect of maxilla;
fo .. foramen in gasbladder capsule;
fs4 .. foramen for the 4th spinal nerve;
fpf .. frontoparietal fontanel;
fr .. frontal;
g .. gap in the supraethmoid;
hh1 .. hypohyal 1;
hh2 .. hypohyal 2;
hbr1 .. } hypobranchs 1, 2, 3;
hbr2 .. }
hbr3 .. }
hp3 .. horizontal process (neural arch ?) from the third vertebral pedicel;
hy .. hyomandibula;
imb .. intermuscular bone;
iop .. interopercular;
ios .. anterior independent sensory canal ossicle;
ios' .. posterior independent sensory canal ossicle;
jf .. jugular foramen;
les .. lateral extrascapular;
let .. lateral ethmoid;
lj .. lacrimojugal;
lje .. lacrimojugal process of lateral ethmoid;
llm .. lateral limb of maxilla;
llp .. lateral limb of premaxilla;
lop .. lateral opening of gasbladder capsule;
lpa .. lacrimojugal process of palatine;
lpt .. united lateral extrascapular and posttemporal;
lsc .. lateral semicircular canal;
max .. maxilla;
mp .. metapterygoid;
mr .. median rostral;
n .. nasal;
na2 .. } neural arch 2, 3 and 4;
na3 .. }
na4 .. }
ns3 .. neural spine 3
oa .. opercular arm;
oan .. outline of angular;
oc .. occipital sensory canal;
oeb1 .. } outline of the epibranchs, 1, 2, 3 and 4;
oeb2 .. }
oeb3 .. }
oeb4 .. }
oec .. outline of ectopterygoid;
oep .. outline of epiotic;
oet .. outline of ethmoid;
of .. optic foramen;
olm .. outline of lateral limb of maxilla;
on .. outline of nasal;
op .. operculum;
opa .. outline of prepalatine;
opet .. outline of first preethmoid;
opl .. outline of palatine;
opt .. outline of pterotic;
opt' .. outline of posttemporal;
op2 .. outline of second preethmoid;
os .. orbitosphenoid;
ose .. outline of supraethmoid;
ost .. outline of supratemporal;
p .. anteromedian process of supra ethmoid;
pa .. parietal;
pa' .. sensory canal passage in the angular;
pal .. palatine;
pah .. articular facet for the hyomandibula in the pterotic;
pas .. parasphenoid;
pb12 .. united pharyngobranchs 1 and 2;
pb34 .. united pharyngobranchs 3 and 4;
pc4 .. winglike projection from the fourth centrum;
pet .. first preethmoid;
pet2 .. second preethmoid
pgb .. posterior gasbladder;
ph2 .. process from the posterior hypohyal;
php .. lateral projection from the basioccipital;
phy .. articular head of hyomandibula with the pterotic facet;
pll .. maxillary process for the ligament of the adductor mandibulae muscle;
pls .. plourosphenoid;
pmp .. posterior process of metapterygoid;
pmx .. premaxilla;
pmy .. posterior myodome;
pop .. preopercular;
ppa .. prepalatine;
ppm .. process of maxilla for articulation of the prepalatine;
ppv .. posterior process of prevomer;
pq .. posterior process of quadrate;
pr .. process of the maxilla;
pro .. prootic;
prp .. palatine facet for articulation of prepalatine;
psc .. posterior semicircular canal;
pt .. posttemporal;
pte .. pterotic;
q .. quadrate;
r2 .. ridge formed on the ventral aspect of the second vertebra (its dorsal rib ?);
ra .. retroarticular;
ri .. ridge in the metapterygoid;
ri' .. ridge in the entopterygoid;
ros .. rostral;
rpm .. rostral process of maxilla;
rpp .. rostral process of premaxilla;
sa .. sesamoid angular;
sah .. articular facet in the sphenotic;
sb .. sesamoid bone;
sc .. sensory canal ossicle;
sca .. scaphium;
scl .. supracleithrum;
se .. supraethmoid;
shy .. hymandibular facet for articulation with the sphenotic;

sm .. symphysis meckelii;
so .. supraoccipital;
so1 .. } suborbital sensory canal ossicles
so8 .. } 1–8;
soc .. suparorbital sensory canal;
soe .. united suspensorial and esophageal processes of fourth vertebra;
soo .. suborbital sensory canal ossicles;
sop .. subopercular;
sp .. sphenotic;
spr .. sphenotic process;
ste .. supratemporal;
stf .. subtemporal fossa;
suo .. supraorbital;
sup .. supraoccipital process;
sy .. symplectic;
tc .. temporal canal;
tf .. trigeminofacialis foramen;
tri .. tripus.

SKELETON OF CYPRINOID FISHES IN RELATION TO PHYLOGENETIC STUDIES.

IV. The skull and other skeletal structures of Gastromyzonid Fishes.

By L. S. Ramaswami, *Senior Research Fellow, N.I.S.I., Department of Zoology, Central College, Bangalore.*

(Communicated by Dr. S. L. Hora, D.Sc., F.N.I.)

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Introduction.

In a previous paper (Ramaswami, 1948), I described the structure of the skull of *Gastromyzon* Günther and compared it with that in a few genera of Homalopteridae that I had examined. Subsequently Dr. S. L. Hora, Director, Zoological Survey of India, Calcutta, made available to me a number of Homalopterid and Gastromyzonid genera for elucidating, from the view-point of skeletal anatomy, their origin and interrelationships.

According to Fang (1935), the Gastromyzonids are a polyphyletic assemblage of individuals, divisible into two groups, viz., the Crossostoma-association and the Gastromyzon-association. Of these two, the Crossostomid fishes derived from 'Nemachiloid ancestral stocks' evolved in three different lines. Fang also traced their interrelationships.

In describing the Homalopterid fishes, Hora (1932) noted that the Homalopteridae (= Homalopterinae, Hora, 1932) evolved from some Cyprinid ancestor while the Gastromyzonidae (= Gastromyzoninae, Hora, 1932) arose from some Cobitid stock and that the members of the Homalopterinae and Gastromyzoninae were probably polyphyletic, resembling one another only superficially due to similarity in life habits. Later Hora (1950), stressing the necessity for treating the two subfamilies independently, discussed in a thought-provoking paper (Hora, MS.) the polyphyletic origin of the Gastromyzonid fishes of the mainland of Asia and Borneo, a draft of which he very kindly made available to me. It is noticed that in the paper referred to above, Hora has taken examples all of which belong to the Gastromyzon-association of Fang (1935) and none to the Crossostoma-association.

Berg (1947), as recorded in my previous paper (Ramaswami, 1951*c*, in press), treated both the subfamilies Homalopterini and Gastromyzonini under the same family Homalopteridae.

Law (1950), after studying the scale structure in both the Crossostoma-association and Gastromyzon-association, came to the conclusion that specialisation had taken place independently among the genera. Further, according to him, the scales of *Gastromyzon* in general were of the Cobitid type and that the scales of *Beaufortia* differed from those of all the other Gastromyzonid fishes.

Having studied the skeletal structure of a number of Homalopterid genera (Ramaswami, 1951*c*, in press), I have been able to point out that a few skeletal structures supported the Cyprinid affiliations of the Homalopteridae. In this paper, I propose to examine the Gastromyzonid skeleton to see if it throws any light on the origin and relationship of the mainland (China) and of the Bornean genera.

Material.

The following Gastromyzonid genera have been studied by me:

A. Bornean forms—

Glaniopsis hanitshi Boulenger; *Protomyzon whiteheadi* (Vaillant); *Gastromyzon borneensis* Günther.

B. Mainland or Chinese forms—

Vanmanenia caldwelli (Nichols); *Crossostoma davidi* Sauvage; *Pseudogastromyzon fasciatus* (Sauvage); *Beaufortia levertti* (Nichols and Pope).

This classification does not give us an idea of the *Crossostoma*- and *Gastromyzon*-associations created by Fang (1935). Under the latter, the first group includes *Annamia* Hora, *Parhomaloptera* Vaillant, *Linparhomaloptera* Fang, *Vanmanenia* Hora, *Praeformosania* Fang, *Formosania* Oshima and *Crossostoma* Sauvage. The second group comprises *Sewellia* Hora, *Paraprotomyzon* Pellegrin and Fang, *Pseudogastromyzon* Nichols, *Protomyzon* Hora, *Neogastromyzon* Popta, *Gastromyzon* Günther and *Beaufortia* Hora. This grouping is entirely based on the fact whether the gill opening extends to the ventral aspect in front of the pectoral fins (Crossostomid group) or is restricted above the bases of the pectoral fins (Gastromyzonid group). It must be noted that *Glaniopsis* is not included under either of these groupings; of the Bornean forms, it is also clear that I have examined examples belonging to both the groups. One peculiarity of the distribution of these forms is that the mainland forms are not represented on the island of Borneo and *vice versa*. For purposes of comparison, I have also studied the skeleton of the loaches *Nemachilus dayi* Hora and *Nemachilichthys ruppelli* (Sykes) [Nemachilini: Cobitidae].

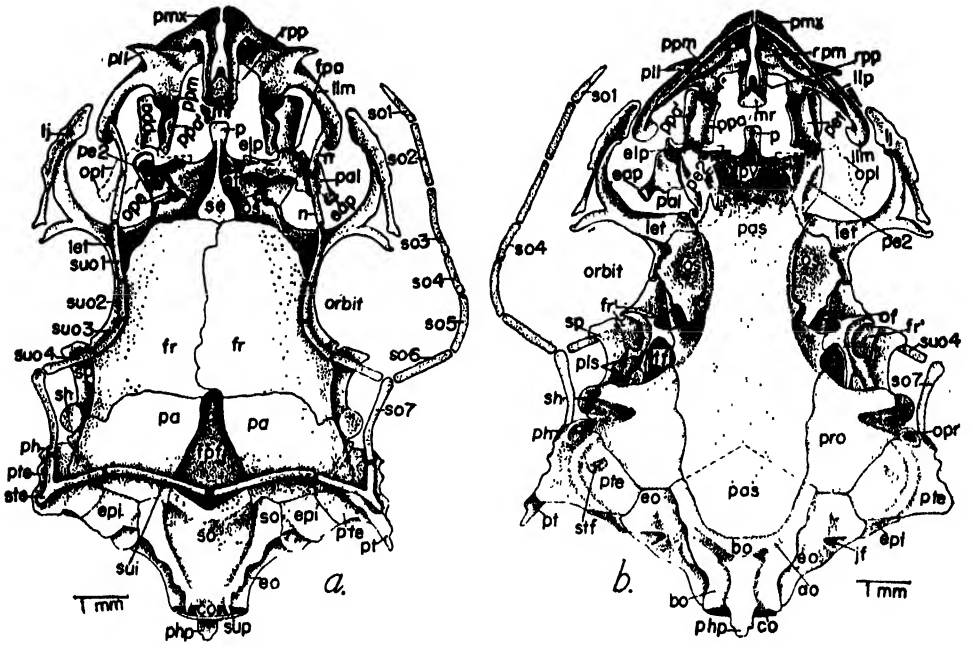
Observations.

I shall not describe the Bornean and Chinese forms separately but shall take them collectively and give a comparative account of the osteological features.

The ethmoid region.—In the Gastromyzonid genera examined, *Glaniopsis* (fig. 1*a*), *Protomyzon* (fig. 2*a*) and *Vanmanenia* (fig. 3*a*) show the firmly articulated supraethmoid part (*se*) which, however, is not very broad; in *Glaniopsis* the supraethmoid resembles that in *Nemachilus* (Cobitidae). While the median prolongation of the supraethmoid (*p*) is short in *Protomyzon* (fig. 2*a*) and *Vanmanenia* (fig. 3*a*), it is long in *Glaniopsis* (figs. 1*a*, 1*b*) as in *Nemachilus*. In *Beaufortia* (figs. 4*a*, 4*b*), *Pseudogastromyzon* (figs. 5*a*, 5*b*), *Crossostoma* (figs. 6*a*, 6*b*) and *Gastromyzon*, the supraethmoid part (*se*) is broad (broader than in the foregoing genera) and the median anterior projection (*p*) is short. Laterally to the supraethmoid part in *Protomyzon* (fig. 2*a*) and *Vanmanenia* (fig. 3*a*), there is the ethmoid (*et*) extension noticed; in *Glaniopsis* (fig. 1*a*), however, this ethmoid extension (*et*) is large and winglike. In *Nemachilus*, the lateral ethmoid extension is not noticed on the dorsal side of the skull. Ventrally the ethmoid (*et*) is visible in *Protomyzon* (fig. 2*b*) and *Vanmanenia* (fig. 3*b*), on the lateral aspect of which the second preethmoid (*pe*2) articulates. In *Glaniopsis* (fig. 1*b*) a small portion of the ethmoid, with the large supraethmoid projection (*p*), is noticed since this region is covered by the asymmetrical prevomer (*pv*) and laterally to the ethmoid, the large second preethmoid (*pe*2) articulates. In *Nemachilus* the ethmoid is not visible ventrally since a large preethmoid covers it.

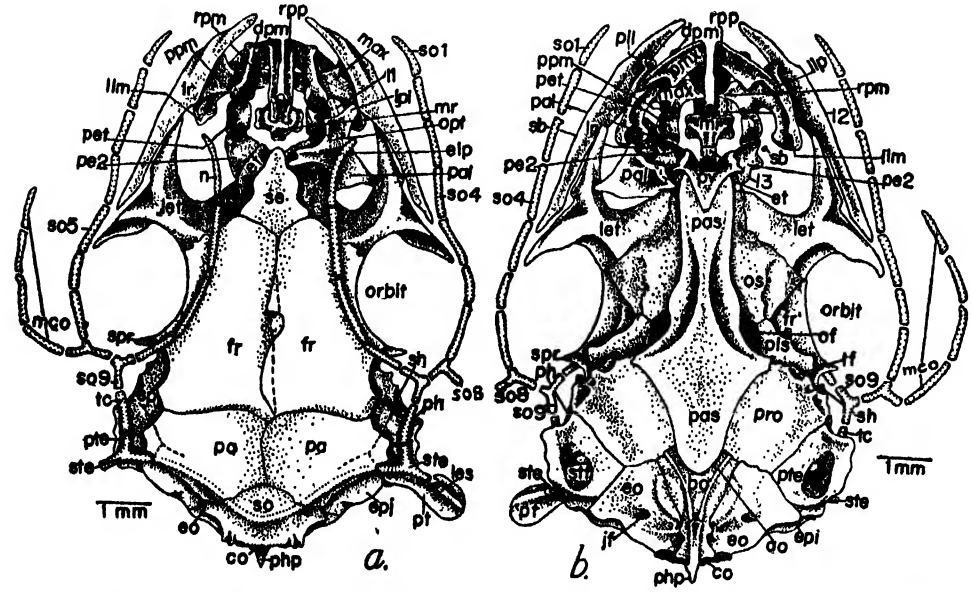
In *Beaufortia* (fig. 4*a*), *Pseudogastromyzon* (fig. 5*a*), *Crossostoma* (fig. 6*a*) and *Gastromyzon* (Ramaswami, 1948), in front of the supraethmoid and also laterally to it in *Beaufortia* (fig. 4*a*) and *Gastromyzon*, the ethmoid (*et*) part is visible dorsally;

ventrally also in the above genera, posteriorly to the large second preethmoid, a small portion of the ethmoid (fig. 4*b et*) is visible.



TEXT-FIGS. 1*a* & 1*b*. Dorsal and ventral views respectively of the skull of *Glaniopsis hanitshi* Boulenger.

Articulating anterolaterally with the ethmoid is the preethmoid bone (figs. 1*a*–6*a*, 1*b*–6*b* *pe*2). I label this as the second preethmoid as there is another one in front of this intercalated between it and the maxilla, which is the first preethmoid (*pet*)



TEXT-FIGS. 2*a* & 2*b*. Dorsal and ventral views respectively of the skull of *Protomyzon whiteheadi* (Vaillant).

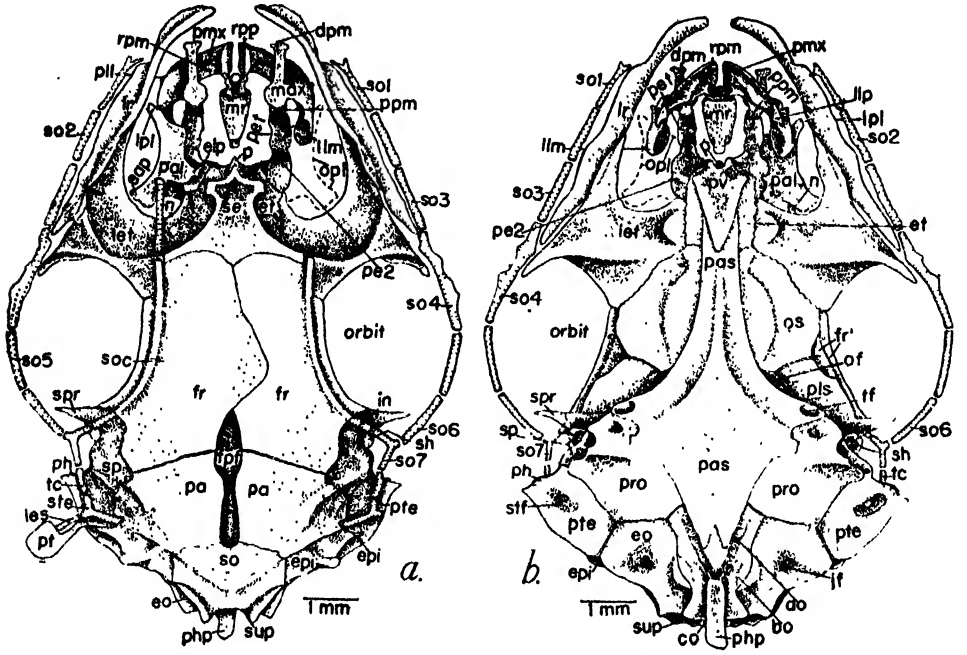
in all the genera examined by me. I have given reasons for considering these two as the first and second preethmoids in my previous paper (Ramaswami, 1951*c*). In *Glaniopsis* (figs. 1*a*, 1*b*) dorsally to the first preethmoid, which, however, is visible only in the ventral view (fig. 1*b pet*), there are two prepalatines (*ppa*, *ppa'*), the lateral of which (*ppa*) articulates posteriorly with the palatine (*pal*) and is free anteriorly while the mesial (*ppa'*) articulates with the prepalatine process of the maxilla (*ppm*) anteriorly and is free posteriorly. It is possible that a single ossification has split longitudinally to give rise to these two prepalatines. In *Nemachilus*, articulating with the maxilla and palatine and sitting laterally upon the first preethmoid, is a single prepalatine. In *Crossostoma*, however, there is a single prepalatine (figs. 6*a*, 6*b ppa*) on either side which while showing an articular facet towards the palatine does not reach the maxilla (*max*) anteriorly. In *Protomyzon*, *Vanmanenia*, *Beaufortia*, *Pseudogastromyzon* and *Gastromyzon*, the prepalatines are absent. It is interesting to note that of the examined genera only one member of the *Crossostoma*-association shows the prepalatine while *Vanmanenia* and the entire *Gastromyzon*-association are free from it.

The premaxillae show the elongated [*Glaniopsis* (fig. 1*a*), *Protomyzon* (fig. 2*a*), or comparatively short *Vanmanenia* (fig. 3*a*)] rostral processes (*rpp*) and the lateral limb (*llp*) may be short as in *Protomyzon* (fig. 2*b*), *Vanmanenia* (fig. 3*b*), *Beaufortia* (fig. 4*b*), *Pseudogastromyzon* (fig. 5*b*) or excessively long as in *Glaniopsis* (fig. 1*b*) and *Crossostoma* (fig. 6*b*). In *Gastromyzon* (Ramaswami, 1948) peculiarly the rostral process reaches the anterior edge of the cruciform median rostral while the lateral limb extends as far as the middle of the lateral ethmoid, a feature not noticed in any other Gastromyzonid examined.

The maxilla shows the characteristic Cyprinid processes in *Protomyzon* and *Vanmanenia*; the long and prominent dorsal premaxillary process (figs. 2*a*, 3*a*, 2*b*, 3*b dpm*) on which is the palatine ligament inserted (fig. 3 *ll*); the process (figs. 2*b*, 3*a pll*) for the insertion of the ligament of the adductor mandibulae muscle; the ventral rostral process (figs. 2*a*, 2*b*, 3*a*, 3*b rpm*) and posteromesially the rounded head (*ppm*) for the articulation of the first preethmoid (*pet*). In *Glaniopsis*, while the dorsal premaxillary process is absent as in *Nemachilus*, the process for the adductor muscle ligament (figs. 1*a*, 1*b pll*) is very prominent and the other processes are normally developed. In *Beaufortia* and *Pseudogastromyzon*, the dorsal premaxillary process (figs. 4*a*, 5*a dpm*) is well developed though not so prominently as in *Protomyzon* and *Vanmanenia*; the process for the adductor mandibulae muscle ligament (figs. 4*a*, 5*a*, 4*b*, 5*b pll*) is poorly developed. In *Crossostoma*, the dorsal premaxillary process (figs. 6*a*, 6*b dpm*) is short and broad while the process for the ligament (*pll*) is prominent and projects posteriorly. In *Gastromyzon* (Ramaswami, 1948, fig. 23), the ventral rostral process (*mp*) is very short resembling that in *Protomyzon* (fig. 2*b*, *rpm*); the dorsal premaxillary process in *Gastromyzon* (Ramaswami, 1948, fig. 23 *rp"*) is quite large and the lateral limb peculiarly possesses a conspicuous lateral process (*lp*) projecting from the middle of it not seen in any other Gastromyzonid form. This probably represents the process for the adductor mandibulae muscle ligament.

The prevomer is small in *Protomyzon* (fig. 2*b pv*) and *Vanmanenia* (fig. 3*b pv*) with a small posterior projection. In *Glaniopsis* (fig. 1*b pv*), the bone is asymmetrical and has no posterior limb. In *Nemachilus*, the posterior limb is very long. In *Gastromyzon* (Ramaswami, 1948), the prevomer is small and shows three short posterior projections of which the mesial is the longest and probably represents the posterior limb of other forms. In *Beaufortia* (fig. 4*b*) and *Pseudogastromyzon* (fig. 5*b*), the prevomer is Y- or V-shaped with a deep depression anteriorly and in the latter example, the posterior limb is almost absent; in *Beaufortia*, the posterior limb (fig. 4*b ppv*) is long and in *Crossostoma*, the prevomer (fig. 6*b ppv*) is large with a projection laterally towards the second preethmoid (*pe2*) and the posterior limb (*ppv*) is also broad.

In the Gastromyzonidae, the lacrimojugal is even larger than that in the Homalopteridae. In the examples of the latter family, I pointed out (Ramaswami,



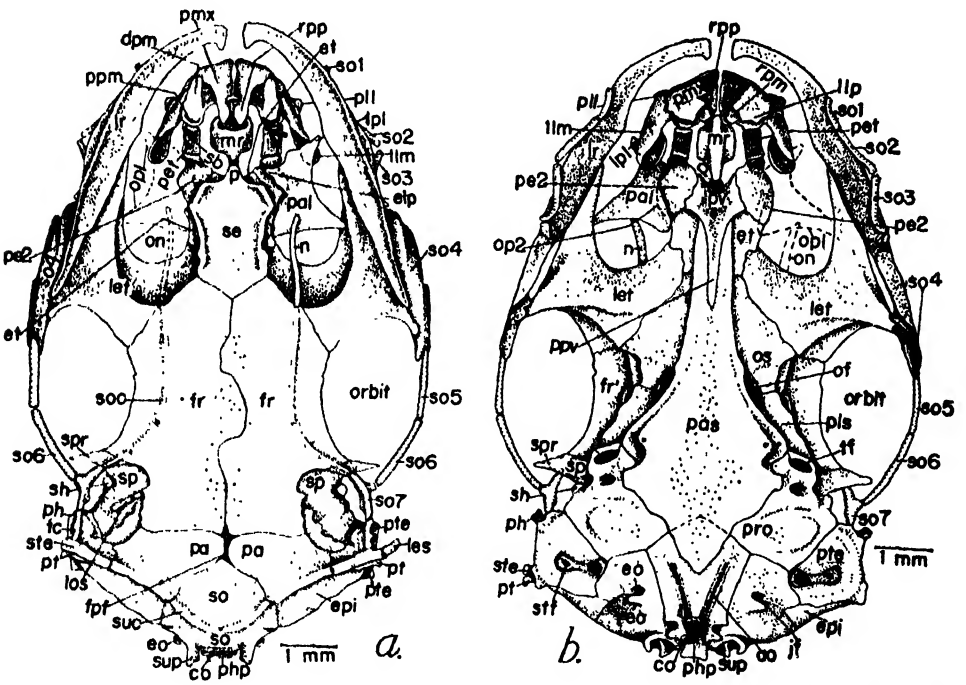
TEXT-FIGS. 3*a* & 3*b*. Dorsal and ventral views respectively of the skull of *Vanmanenia caldwelli* (Nichols).

1951*c*, in press) that the lacrimojugal was devoid of a sensory canal in it and the bone was definitely larger in size than that in the Cyprinidae. In *Protomyzon* (figs. 2*a*, 2*b*), *Vanmanenia* (figs. 3*a*, 3*b*) and *Crossostoma* (figs. 6*a*, 6*b*), the lacrimojugal-rostral is of one size and it assumes even larger proportions in *Gastromyzon* (Ramaswami, 1948), *Beaufortia* (figs. 4*a*, 4*b*) and *Pseudogastromyzon* (figs. 5*a*, 5*b*) where each lacrimojugal-rostral takes a bend mesially; there is also a small spinelike process laterally in *Gastromyzon*. It is likely that this large bone is a composite one formed at least by the union of a large lacrimojugal and a rostral; in the Homalopterid examples there is a large lacrimojugal in front of which there is a rostral and it was assumed that the former was formed by the union of a lacrimal and a jugal. In the Gastromyzonidae, I have labelled this large bone as lacrimojugal-rostral. In *Glaniopsis* (figs. 1*a*, 1*b lj*), the lacrimojugal is not very big resembling that in the Homalopteridae and does not extend as far as the premaxilla and a rostral is also absent in front of it. It looks, therefore, more like the Homalopterid lacrimojugal in size with the sensory canal ossicle independently situated. In *Nemachilus*, the anterior rostral is small with a long lacrimojugal behind and the sensory canal ossicles are situated laterally to the lacrimojugal. Chranilov (1927) showed only a 'preorbital' in *Nemachilus barbatulus* and did not refer to the sensory canal ossicles and the same figure has been reproduced by Berg (1947, p. 267). In *Beaufortia* (figs. 4*a*, 4*b so1–so4*) and *Gastromyzon* (Ramaswami, 1948), the lacrimojugal is very closely associated with the sensory canal bones of the infraorbital series.

The lateral ethmoid (*let*) is well developed in *Protomyzon* (figs. 2*a*, 2*b*), *Vanmanenia* (figs. 3*a*, 3*b*), *Beaufortia* (figs. 4*a*, 4*b*), *Pseudogastromyzon* (figs. 5*a*, 5*b*) and *Crossostoma* (figs. 6*a*, 6*b*); the lacrimojugal-rostral process of the lateral ethmoid is more well developed in all than the posterior process; in *Nemachilus*, the lateral ethmoid is also small with both the processes short. In Gastromyzonidae (except

Glaniopsis), one is struck with the width of the lateral ethmoid as opposed to that in the Homalopteridae and in *Nemachilus*.

As in the Homalopteridae, the palatine (*pal*) shows a process (figs. 1*a*, 1*b*, 2*a*, 3*a*, 4*a*, 5*a*, 6*a elp*) towards the ethmoid and this process is very small in *Vanmanenia* (fig. 3*a*) and *Beaufortia* (fig. 4*a*). There is one towards the entopterygoid (figs. 1*a*, 3*a*, 6*a*, 1*b*, 5*b*, 6*b eap*) and the bone articulates ventromesially with the second preethmoid (*pe*2). In *Protomyzon* (fig. 2*a*), *Vanmanenia* (figs. 3*a*, 3*b*), *Beaufortia* (figs. 4*a*, 4*b*), *Pseudogastromyzon* (figs. 5*a*, 5*b*) and *Gastromyzon* (Ramaswami, 1948), it also shows anterolaterally a process (*lpl*) towards the lacrimojugal-rostral. However, in *Crossostoma* (figs. 6*a*, 6*b*), such a process is absent. In *Glaniopsis*, the diminutive palatine shows the processes described above except the lacrimojugal process. In this and in *Crossostoma*, since a prepalatine (or prepalatines) is noticed, the palatine also shows a rounded articulating facet (figs. 1*a*, 6*a fpa*) anteriorly for articulation with the prepalatine.



TEXT-FIGS. 4*a* & 4*b*. Dorsal and ventral views respectively of the skull of *Beaufortia levertti* (Nichols and Pope).

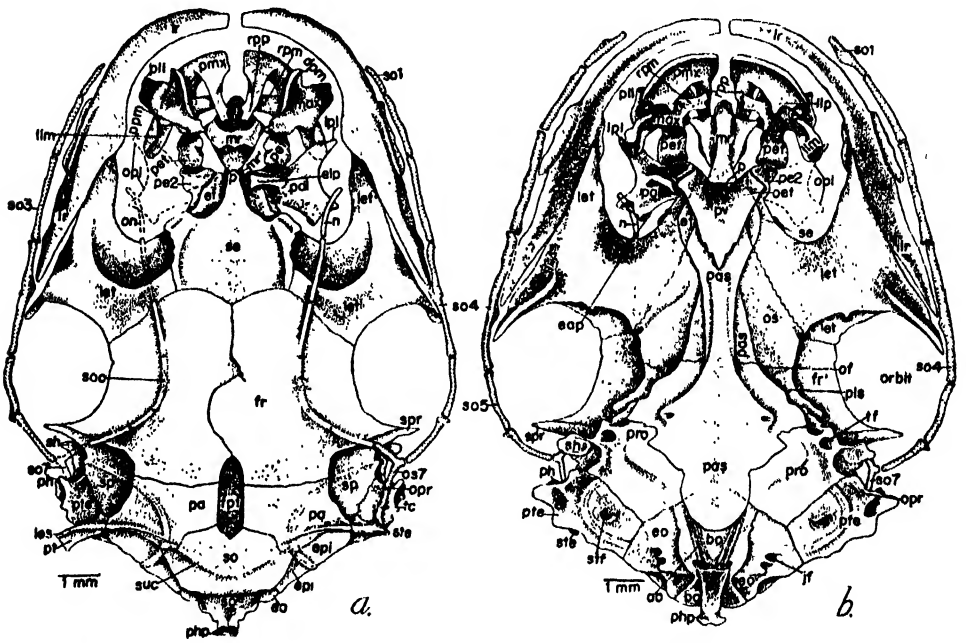
The nasal (*n*) is represented in all these forms by one (figs. 2*a*–6*a*, 4*b*–6*b* *n*) or two small canal bones as in *Glaniopsis* (fig. 1*a n*).

In *Protomyzon* (figs. 2*a*, 2*b* *mr*) and *Gastromyzon* (Ramaswami, 1948), the median rostral is cruciform; in *Vanmanenia* (figs. 3*a*, 3*b*), it is elongated and broad where the limbs of the premaxillae rest. In *Beaufortia* (figs. 4*a*, 4*b*), it is also large and may be described as cruciform with the posterior portion situated ventrally to the median projection (*p*) of the supraethmoid (*se*); similarly in *Pseudogastromyzon* (figs. 5*a*, 5*b*), the median rostral is large and the posterior projection (*mr'*) lies below the supra-ethmoid extension (*p*). In *Crossostoma* (figs. 6*a*, 6*b*) and *Glaniopsis* (figs. 1*a*, 1*b*), it is small and roughly triangular.

The orbitotemporal region.—The general flattening of the skull has resulted in the widening of the frontals and parietals; the frontals (figs. 1*a*–6*a*, 1*b*–6*b* *fr*) extend laterally in the orbital region so much that on the ventral aspect also a large part of the bone (*fr'*) is visible.

In *Glaniopsis* (fig. 1*a*), *Vanmanenia* (fig. 3*a*), *Pseudogastromyzon* (fig. 5*a*) and *Crossostoma* (fig. 6*a*), a large fontanel (*fpf*) is included between the frontals anteriorly, the parietals laterally and the supraoccipital posteriorly. In *Glaniopsis* (fig. 1*a*), the fontanel is broad posteriorly and the two independent supraoccipital sensory canal ossicles lie over the fontanel; in *Beaufortia* (fig. 4*a*), the fontanel (*fpf*) is a chinklike space. In *Nemachilus* also a frontoparietal fontanel is present.

Generally flanking the frontals on either side in the Cyprinidae, Psilorhynchidae and Homalopteridae, there is the supraorbital. In Gyrinocheilidae, the Gastromyzonidae (except *Gastromyzon*) and in *Nemachilus*, a supraorbital is absent. In *Gastromyzon* (Ramaswami, 1948), however, the supraorbital is a very small sickle-shaped bone.



TEXT-FIGS. 5*a* & 5*b*. Dorsal and ventral views respectively of the skull of *Pseudogastromyzon fasciatus* (Sauvage).

Ventrally the orbitosphenoids (figs. 1*b*–6*b* *os*) and the pleurosphenoids (*pls*) are prominent. The optic foramen (*of*) is included between the orbitosphenoid, the pleurosphenoid and the parasphenoid (*pas*). In all these forms, an interorbital septum is absent on account of the general flattening of the skull. Peculiarly in one species of Homalopteridae, *Homaloptera amphisquamata* (Ramaswami, 1951*c*, in press), an interorbital septum is noticed. In *Nemachilus* also an interorbital septum is absent; the orbitosphenoids are united and is a single ossification as in other Cobitidae.

The parasphenoid (figs. 1*b*–6*b* *pas*) is broad posteriorly and narrow anteriorly [*Vanmanenia* (fig. 3*b*), *Beaufortia* (fig. 4*b*)] or broad posteriorly and the anterior portion is also broader than in the previous examples [*Glaniopsis* (fig. 1*b*), *Protomyzon* (fig. 2*b*)] or broad both anteriorly and posteriorly with a waist [*Pseudogastromyzon* (fig. 5*b*), *Crossostoma* (fig. 6*b*), *Gastromyzon* (Ramaswami, 1948)]. Thus the shape of the parasphenoid is not uniform in the family.

The eye muscle canals are noticed in all these examples; the position of the two canals, *viz.*, the anterior myodome and the posterior myodome, is indicated only in the ventral view of *Crossostoma* (fig. 6*b* *amy*, *pmy*). In *Nemachilus* also the two poorly developed myodomes are seen.

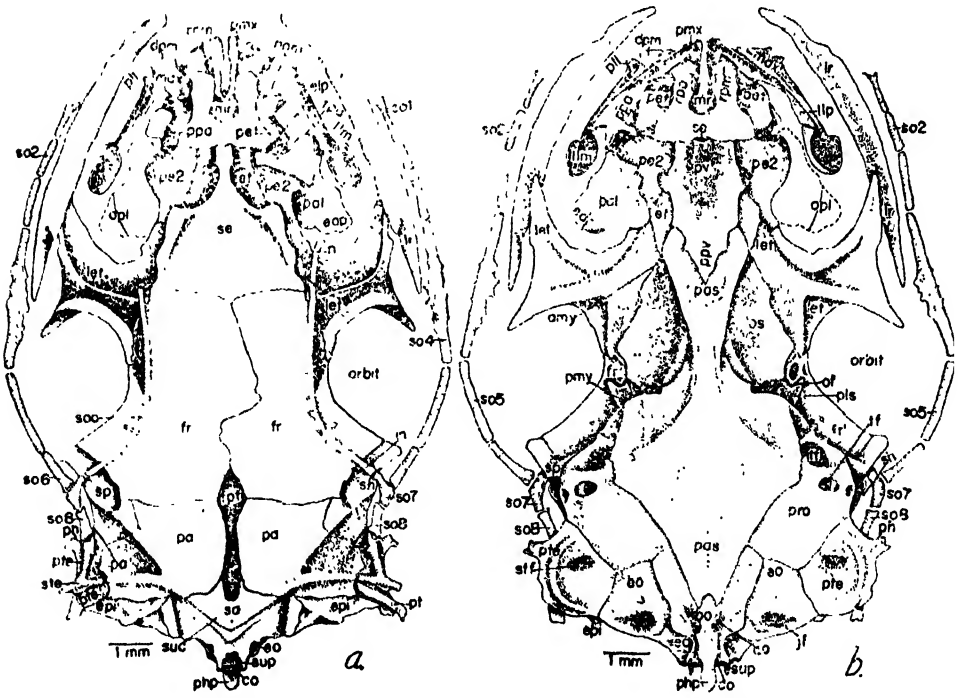
There are two deeply cupshaped large sclerotic bones in each bulbus oculi.

The auditory region.—As in other groups of hillstream fishes like the Homalopteridae, Psilorhynchidae* and Gyrinocheilidae, this region is formed by the sphenotic anterolaterally, the pterotic laterally, the epiotic posteriorly and the prootic bones ventrally of the auditory region; an opisthotic is absent.

The sphenotic generally shows a deep fossa (figs. 1*a*–6*a*, 1*b*–6*b* *sh*) for giving articulation to the anterior head of the hyomandibula and the posterior articulation of the latter is in the sphenotic-pterotic region. It may be a fossa as in *Protomyzon* (fig. 2*b* *ph*), *Beaufortia* (fig. 4*b* *ph*) and *Pseudogastromyzon* (fig. 5*b* *ph*) or a surface for articulation as in *Glaniopsis* (figs. 1*a*, 1*b* *ph*), *Vanmanenia* (figs. 3*a*, 3*b* *ph*) and *Crossostoma* (figs. 6*a*, 6*b* *ph*). In *Nemachilus*, the two are always fossae for the bosslike projections of the hyomandibula to articulate.

The sensory canals.—In *Glaniopsis* (fig. 1*a*), the supraorbital, the temporal and the supraoccipital canals are composed of a set of independent ossicles. In the nasal region there are two ossicles (*n*) and in the supraorbital region there are four (*suo*1–*suo*4) and the last of this series leads laterally into the infraorbital canal (*so*1–*so*6) and posteriorly into the temporal canal ossicle (*so*7) The long temporal canal (*so*7) ossicle meets the triradiate supratemporal ossicle (*ste*) which leads mesially into the occipital ossicle (*sui*) and laterally into the lateral extrascapular which, however, is not drawn in the figure.

In *Protomyzon* also the supraorbital sensory canal ossicles are independent as in *Glaniopsis* and the triradiate ossicle in the sphenotic region (fig. 2*a* *so*9) leads into an independent one sitting on the pterotic (*tc*) which in turn leads on to a triradiate ossicle,—the supratemporal (*ste*); the supraoccipital canal is not composed of independent ossicles as in *Glaniopsis*.



TEXT-FIGS. 6*a* & 6*b*. Dorsal and ventral views respectively of the skull of *Crossostoma davidi* Sauvage.

* *Psilorhynchus* is also known to burrow in sand.

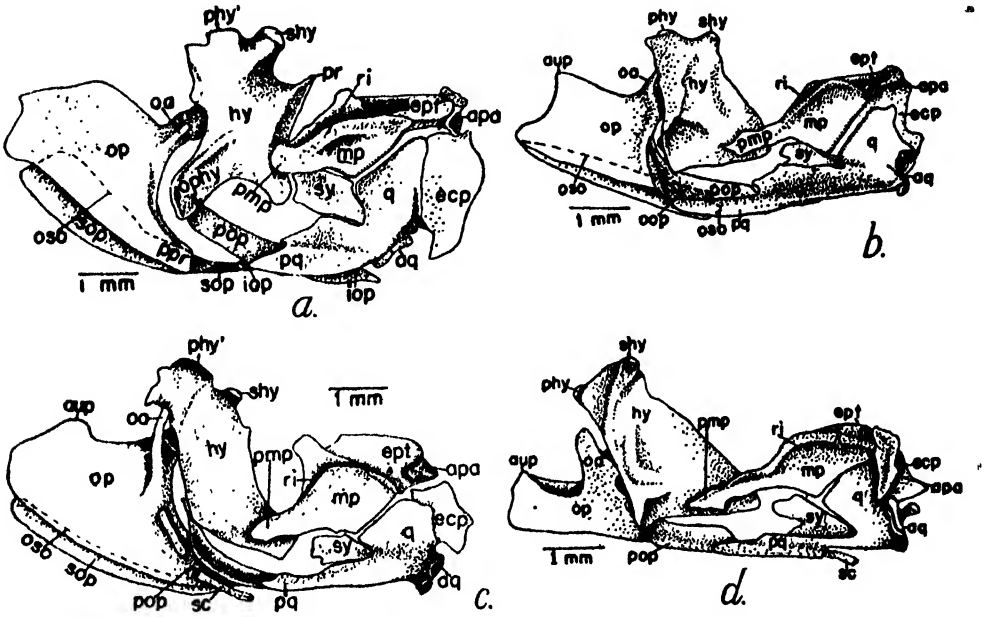
In *Vanmanenia* (fig. 3*a*), *Crossostoma* (fig. 6*a*) and *Gastromyzon* (Ramaswami, 1948), the supraorbital canal (*soc*) is incorporated in the frontal and this extends into a small ossicle on the sphenotic (*in*) as in the Homalopteridae, connecting a triradiate one (*so*7) which in turn is connected with a triradiate supratemporal (*ste*) through a small ossicle (fig. 3*a tc*; fig. 6*a so*8) disposed on or in front of the pterotic. In *Pseudogastromyzon* (fig. 5*a*) the supraorbital canal which is noticed in the frontal leads into a triradiate ossicle (*so*7) which in turn leads into an ossicle (*tc*) on the pterotic which is connected with the supratemporal (*ste*) which, however, is not triradiate. In *Beaufortia* (fig. 4*a*), the supratemporal is also not triradiate and the sensory canal passes in front of this in the pterotic (*tc*) and is connected with the triradiate ossicle (*so*7). The supraorbital canal (*soc*) is noticed in the frontal. Peculiarly towards the posterolateral edge of the frontal in *Beaufortia*, there are two sensory canal ossicles sitting on the sphenotic (*ios*) with apparently no connection either with the supraorbital canal or with the triradiate ossicle (*so*7). What exactly is the nature of these ossicles, I am at present unable to say. In no other Gastromyzonid have I noticed such a feature. In *Nemachilus*, the supraorbital sensory canal leads into the suborbital by an independent ossicle sitting on the sphenotic region; the supratemporal is triradiate and leads into the supraoccipital canal mesially and the temporal canal anteriorly in the pterotic.

The pterotic shows a feeble depression ventrally in *Gastromyzon* (Ramaswami, 1948), *Glaniopsis* (fig. 1*b*), *Vanmanenia* (fig. 3*b*), *Beaufortia* (fig. 4*b*) and *Crossostoma* (fig. 6*b*) representing the subtemporal fossa (*stf*), but in *Protomyzon* (fig. 2*b*) the subtemporal fossa (*stf*) seems to be better developed. This fossa is for the insertion of the hyobranchial muscles. While in all these examples the hyobranchial apparatus is well developed, the feeble development of the subtemporal fossa in the majority of the Gastromyzonidae becomes difficult to explain.

As in the Homalopteridae, the exoccipital (figs. 1*a*–6*a*, 1*b*–6*b eo*) is excluded from forming the roof of the foramen magnum in Gastromyzonidae. The supraoccipital (*so*) may project posteriorly as two processes (*sup*). The exoccipitals do not disclose the fontanel so commonly seen in the catostomids, the cyprinids and the cobitids. The basioccipital (*bo*) shows a prominent pharyngeal process (*php*) and the dorsal aorta running dorsally to this divides anteriorly into two branches (*ao*). In *Glaniopsis* also such an arrangement is noticed resembling *Nemachilus*.

The upper jaw.—The palatine bone has already been described. The upper jaw of *Glaniopsis* shows certain features in which it stands apart from the other Gastromyzonid genera and resembles more *Nemachilus*. The operculum (fig. 7*a op*) projects by an anterior process (*ppr*) and articulates with the hyomandibula by a prominent socket near which there is a spinelike articular process (*oa*). A process from the posterodorsal edge of the operculum called the auricular process is absent. The hyomandibula (*hy*) shows a large boss by which it fits into a socket in the sphenotic (*shy*) and a flat facet (*phy'*) for articulation with the pterotic region. There is also a prominent process (*pr*) in front of the sphenotic articulation. From the ventral border of the hyomandibula, there arises a prominent backwardly directed process (*ophy*) with which the preoperculum (*pop*) comes in contact. Such a process is not seen in the other Gastromyzonid examples. However, in *Nemachilus*, such an opercular process of the hyomandibula is noticed. The quadrate (*q*) has a short and broad posterior limb (*pq*). The metapterygoid (*mp*) has a very short limb (*pmp*) towards the hyomandibula (*hy*). In *Pseudogastromyzon* (fig. 8*a*), the operculum shows prominent auricular (*aup*) and articular (*oa*) processes; the hyomandibula (*hy*) and the preopercular (*pop*) are large, the posterior process of the quadrate (*pq*) is long and the symplectic (*sy*) is small and is wedged in between the metapterygoid (*mp*) and the quadrate (*q*). The hyomandibula (*hy*) is broad and the boss for articulation with the pterotic region is mesially situated and, therefore, is not shown in the figure. In *Beaufortia* (fig. 7*d*), the articular process (*oa*) is prominent and an auricular process (*aup*) is just indicated. In *Protomyzon*

(fig. 7*b*), *Vanmanenia* (fig. 7*c*), *Crossostoma* (fig. 8*b*), there is a short articular process (*oa*) and the auricular process is just indicated as in *Beaufortia*. The metapterygoid



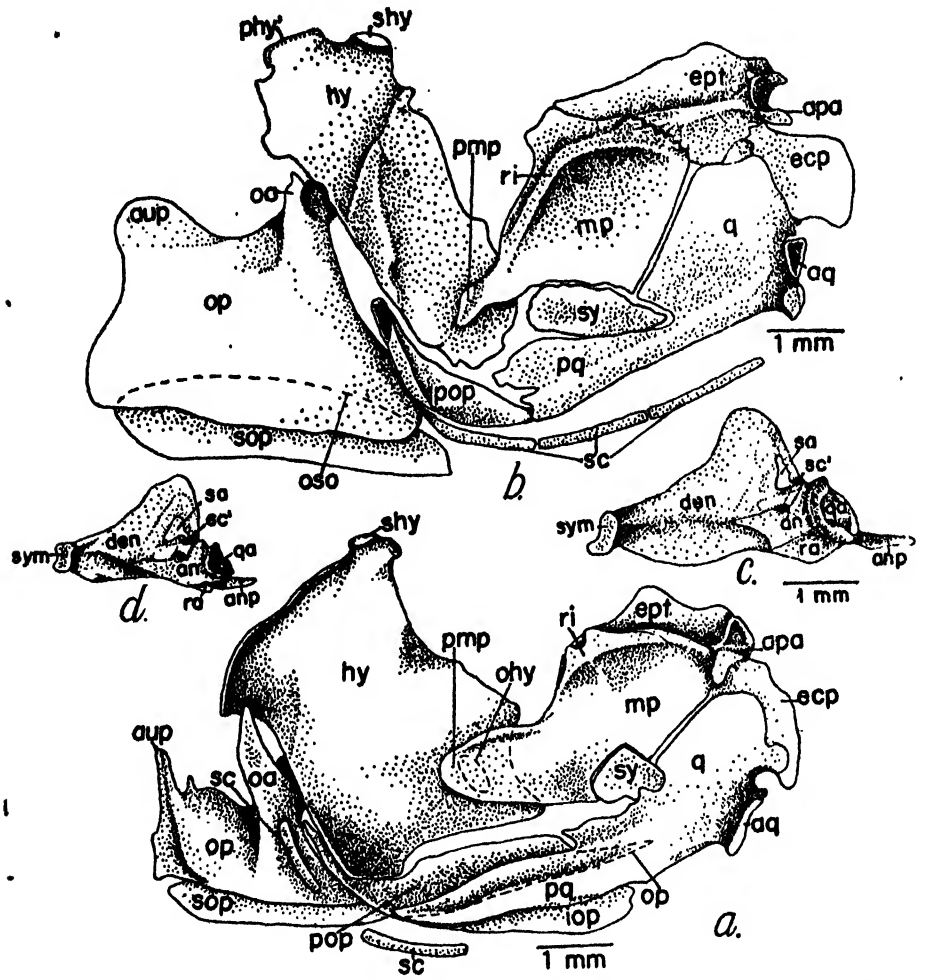
TEXT-FIG. 7*a*. Lateral view of the right upper jaw of *Glaniopsis hanitshi* Boulenger.
,, 7*b*. Lateral view of the right upper jaw of *Protomyzon whiteheadi* (Vaillant).
,, 7*c*. Lateral view of the right upper jaw of *Vanmanenia caldwelli* (Nichols).
,, 7*d*. Lateral view of the right upper jaw of *Beaufortia levertti* (Nichols and Pope).

process (*pmp*) is short and broad in *Pseudogastromyzon* (fig. 8*a*), while in *Glaniopsis* (fig. 7*a*), *Vanmanenia* (fig. 7*c*), *Beaufortia* (fig. 7*d*), *Crossostoma* (fig. 8*b*) and *Gastromyzon* (Ramaswami, 1948), it is narrow. Further, the metapterygoid in all these forms shows a prominent ridge (*ri*); sometimes this ridge may be in continuation of the ridge (*ri'*) on the entopterygoid also as in *Pseudogastromyzon* (fig. 8*a*), *Glaniopsis* (fig. 7*a*), *Beaufortia* (fig. 7*d*) and *Crossostoma* (fig. 8*b*). The hyomandibula may show two articular bosses [*Protomyzon* (fig. 7*b*), *Beaufortia* (fig. 7*d*), *Pseudogastromyzon* (fig. 8*a*) and *Gastromyzon* (Ramaswami, 1948)] or one boss (*shy*) and one facet (*phy'*) as in *Glaniopsis* (fig. 7*a*), *Vanmanenia* (fig. 7*c*) and *Crossostoma* (fig. 8*b*). Laterally there may be two independent ossicles (*sc*) as in *Pseudogastromyzon* (fig. 8*a*) and *Vanmanenia* (fig. 7*c*) or three as in *Crossostoma* (fig. 8*b*) or there may be a single one leading from the preopercular in front of the quadrate process as in *Beaufortia* (fig. 7*d*). In *Glaniopsis* (fig. 7*a*) and *Protomyzon* (fig. 7*b*), independent sensory canal ossicles are not noticed. In *Nemachilus*, the opercular is elongated in the anteroposterior direction and shows a prominent articular process; the preopercular is long and shows in front a sensory canal ossicle and the metapterygoid carries a prominent ridge.

The lower jaw.—There is an uniformity in the disposition of the structures of the lower jaw but for the shape of the bones.[1] A large edentulous dentary (figs. 8*c*, 8*d den*), an angular (*an*) with which the quadrate articulates (*qa*), a small retroarticular (*ra*) and a mesially situated sesamoid angular (*sa*) are uniformly noticed in all the genera examined by me. In *Pseudogastromyzon* (fig. 8*c*) and

[1] Berg (1947) while pointing out that the current nomenclature of the bones of the lower jaw of teleosts is incorrect, still prefers to use the same 'to avoid misunderstanding'; however, I have followed in all my papers on fish skull, the correct nomenclature (Haines, 1937).

Beaufortia (fig. 8*d*) only, the angular projects posteriorly in the forms of a process (*anp*). Mesially there is also a canal (*sc'*) in all these forms through which a bristle



TEXT-FIG. 8*a*. Lateral view of the right upper jaw of *Pseudogastromyzon fasciatus* (Sauvage)
,, 8*b*. Lateral view of the right upper jaw of *Crossostoma davidi* Sauvage.
,, 8*c*. Mesial view of the right lower jaw of *Pseudogastromyzon fasciatus* (Sauvage).
,, 8*d*. Mesial view of the right lower jaw of *Beaufortia levertti* (Nichols and Pope).

could be easily passed. This is, probably, the mandibular sensory canal; in the Homalopteridae and the Nemachilinae also there is a mesial sensory canal. In the majority of fishes, however, the mandibular sensory canal is *laterally* disposed.

In the hyobranchial apparatus the arrangement of parts is very much like that in the Homalopteridae (Ramaswami, 1951*c*, in press). Connecting the two pairs of hypohyals, there is a median ossification probably also a part of the basihyal and dorsally to this, a three-pronged basihyal is noticed. There are three copulae usually, three pairs of hypobranchs and two pairs of pharyngobranchs; in *Beaufortia* the median copulae are four in number and in *Glaniopsis*, a small third pharyngobranch ossification is also seen. Dorsal gillrakers extending on the hypobranch and the median copulae are noticed in all the examples. The occurrence of the gillrakers is conspicuously noticed in the Gastromyzonidae and not a single species of Homalopteridae examined by me exhibited this character.

The Weberian apparatus.—As far as I am aware, the Weberian apparatus in no Gastromyzonid example has so far been described. It does not, however, differ from that in the Homalopteridae.

I have already described the arrangement of parts with regard to the gasbladder capsule and the associated Weberian ossicles in the Homalopteridae.

It is noticed that in the nemachiline Cobitidae, Homalopteridae and Gastromyzonidae the gasbladder is completely divided into two and is enclosed in an osseous capsule. Chranilov (1927), having studied the structure of the gasbladder in a number of Cobitid genera, divided them into two structural types. While in the first the capsule is single (*Misgurnus*, etc.), in the second the capsule is divided into two, the two being connected by a posterior commissure as in *Nemachilus*. In the Gastromyzonidae, it is also noticed that projecting from this commissure posteriorly there is a small posterior portion of the gasbladder as in *Beaufortia*, *Protomyzon* (fig. 9*b mgb*) and *Crossostoma*; in *Glaniopsis* and *Pseudogastromyzon*, this posterior portion of the gasbladder is absent. It may also be remarked here that in the Homalopterid, *Homaloptera leonardi*, there is a long posterior portion of the gasbladder and in *H. zollingeri* there is a small oval posterior portion. In *Nemachilus*, Chranilov (1927) showed a large posterior portion.

It has also been remarked by me (Ramaswami, 1952*c*, in press), that the gasbladder capsule of the Homalopteridae and the Gastromyzonidae resembles that in Nemachilini (Cobitidae). In *Nemachilus*, the capsule is formed by the dorsal ribs (transverse processes of previous authors) of the second and fourth vertebrae, the pleural ribs of the second and the ossa suspensoria of the fourth vertebra according to Chranilov (1927). The ossa suspensoria contribute the mesial wall, a part of the lower osseous wall and the wall of the transverse canal; while the dorsal ribs of the second vertebra form the antero-dorsal and the pleural, the antero-ventral walls of the capsule, the dorsal ribs of the fourth vertebra form the postero-dorsal and postero-ventral walls. In *Nemachilus dayi* which I have examined, each half of the gasbladder capsule is composed of the ribs (dorsal and pleural) of the second and fourth vertebrae; the large posterior portion is formed by the dorsal ribs of the fourth vertebra and the smaller anterior portion is formed by those of the second vertebra, the sutural line between the two being clearly visible only anterodorsally. I have also noted such a sutural line in another nemachilid *Nemachilichthys* which I have examined. However, in *Nemachilus*, the disposition of the prominent parapophyses[1] of the second vertebra indicates their extension ventrally and laterally to these, the wall is formed by the pleural ribs. I am unable to make out the contribution of the ossa suspensoria towards the formation of the capsule and the transverse canal. Laterally each capsule shows two openings: an anterior smaller and a posterior larger one (apertura magna externa) through which the gasbladder of the animal can come in contact with the skin.

The neural arch of the second vertebra of *Nemachilus*, whose exact derivation I am unable to say, is noticed middorsally as a keystone arch in front of the third neural arch; the latter is in continuity on either side with the gasbladder capsule. Laterally to the second arch referred to above, the claustrum and scaphium are noticed. The first vertebral centrum carries an independent pair of dorsal ribs. The fourth neural arch, shows a prominent spine and the centrum is also large

[1] Berg (1947) labelled in *Nemachilus strauchi* the 'transverse processes' as parapophyses. The referee has kindly pointed out that 'The term parapophysis indicates the structure which represents the rib-bearing process of the haemal arch. Actually the basiventrals of the anterior region of a fish vertebra are misquoted as parapophyses'. We read in Goodrich (1930, p. 73) that the pleural ribs may articulate with rib-bearing processes of basiventrals as in *Cyprinus* and that these processes arise independently. Whether in *Nemachilus* the so-called parapophyses arise independently and later fuse with the basiventrals or they merely represent the basiventrals, when according to the referee, they should not be called parapophyses, I am unable to say at present as I have not examined developmental stages.

and no indication of the fusion of the third centrum with it is noticeable. The horizontal process described in the Homalopteridae (Ramaswami, 1952*c*, in press), as extending over the paravertebral space in front of the orifice for the fourth spinal nerve and probably arising from the third neural arch, is not seen in *Nemachilus* or *Nemachilichthys*.

In the Bornean Gastromyzonidae like *Glaniopsis* and *Protomyzon*, the sutural demarcation described above between the second and fourth dorsal ribs anterodorsally of the capsule wall is not seen. In the Homalopteridae while *Lepturichthys* and *Homaloptera leonardi* show such a sutural line, *Balitora* and *H. rupicola* do not. However, in *Glaniopsis* and *Protomyzon* the third (plus 2nd?) neural arch is clearly seen and between it and that of the fourth, the spinal nerve orifice discloses the ventrally lying tripus. The 'keystone arch', described in *Nemachilus* as lying in front of the third neural arch, is wanting in the examined genera of Bornean Gastromyzonids[1]. The short centrum of the first vertebra, which is opisthocoelous, carries a pair of independent dorsal ribs. The gasbladder capsule shows laterally paired orifices as in *Nemachilus* and the Homalopteridae. Ventrally the parapophyses of the second vertebra are prominent and no indication of a separate third centrum is noticeable.

The mainland forms show certain peculiarities. In *Vanmanenia* and *Crossostoma*, the dorsal demarcation between the second and fourth rib extensions on the gasbladder is absent; however, the neural arches of those vertebrae could be clearly made out. While in *Crossostoma*, the dorsal ribs of the first centrum are united terminally with the anterior face of the gasbladder capsule, in *Vanmanenia*, the ribs are free. *Pseudogastromyzon* and *Beaufortia* resemble each other closely. The ribs of the first centrum (fig. 9*c dr*1) are fused with the gasbladder capsule and as in the Bornean forms, no sutural demarcation is noticed on the dorsal aspect of the capsule. The neural arches of the second and fourth vertebrae are peculiarly broadened out to form horizontal processes (*ex*24). The transverse canal (*trc*) shows only partial encasement by bone. The claustrum (*cl*) articulates with the anterior face or edge of the second neural arch, the 'keystone arch' being not formed in the above two forms.

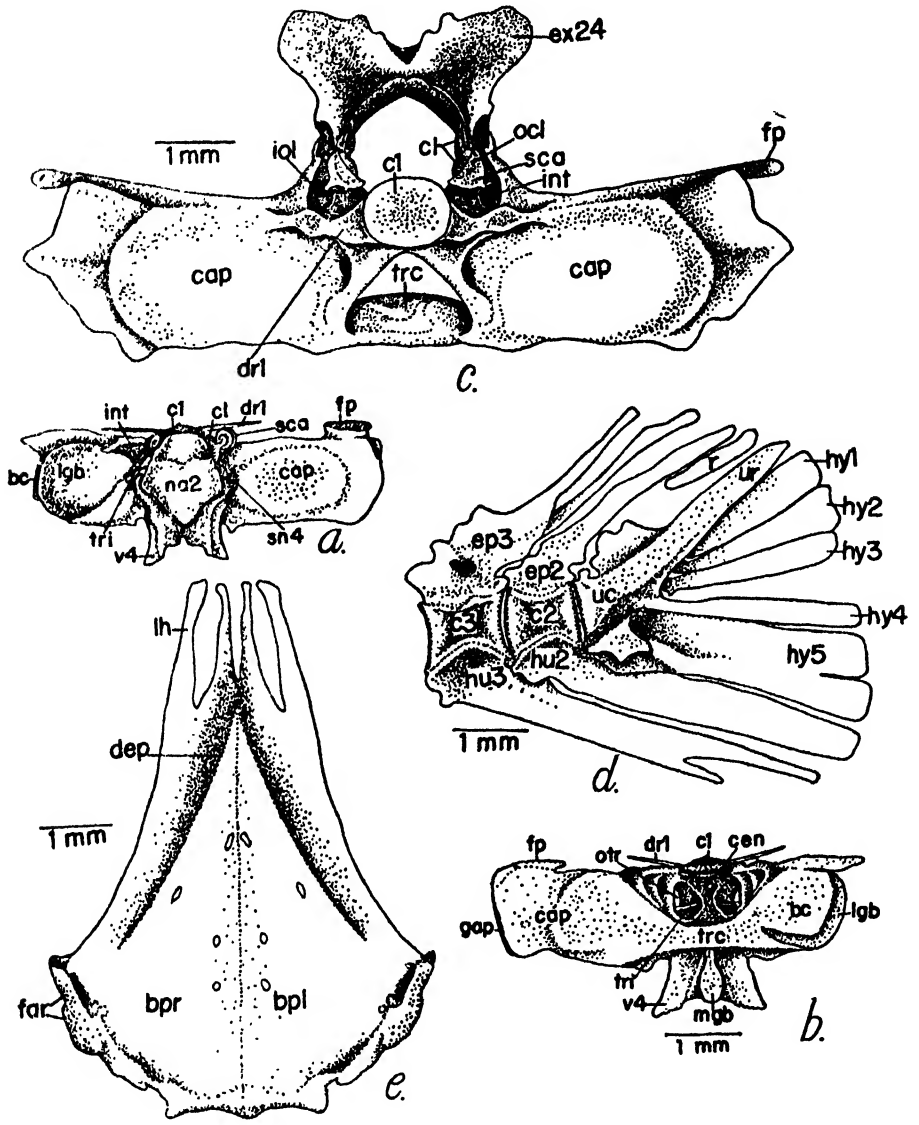
The Gastromyzonid gasbladder capsule differs from that of the Homalopteridae in not possessing a horizontal process extending on the paravertebral space of either capsule from the third neural arch and resembles thereby the Nemachilini.

As in the Cobitidae and Homalopteridae, associated with the second neural arch is the claustrum (figs. 9*a*, 9*c cl*) and between it and the funnel-shaped scaphium (*sca*) the posterior portion of the sinus impar of the united endolymphatic canal is enclosed. The scaphium is in contact with the triradiate tripus (fig. 9*a tri*) through the rodlike intercalarium (figs. 9*a*, 9*c int*) in the interosseous ligament (*iol*). One limb of the triradiate tripus (fig. 9*a tri*) is in contact with the gasbladder without its transmitting process, while the other limb (fig. 9*b tri*) is in contact with the centrum (*cen*) of the fused vertebrae. Probably the derivation of these ossicles is not very different from what has been described by Watson (1939) in the goldfish.

The caudal fin skeleton.—The last three vertebrae support the rays of the caudal fin. The last vertebra, whose anterior face shows a typical concavity characteristic of the piscine vertebra, projects posterodorsally as the urostyle (fig. 9*d ur*). The hypochordal lobe of the caudal fin is therefore larger than the epichordal and the fin is apparently symmetrical. The urostyle has a free radial (*r*) anteriorly usually, but in *Beaufortia* there are two; posteriorly to the urostyle, there are five (fig. 9*d*) or six hypurals (*Glaniopsis*, *Protomyzon*, *Beaufortia*, *Vanmanenia* and *Crossostoma*). The attachment of the hypurals is rather interesting; there are three hypurals (*hy*1–*hy*3) immediately posteriorly to the urostyle articulating with it, the fourth

[1] It is likely that the second neural arch is fused with the third as there is no clear demarcation between the two in the adult.

hypural (*hy4*) is fused with the last vertebral centrum and ventrally to this, there are two hypurals in all Gastromyzonidae (except *Pseudogastromyzon*) of which the



TEXT-FIG. 9*a*. Dorsal aspect of the gasbladder capsule and Weberian ossicles of *Protomyzon whiteheadi* (Vaillant).

,, 9*b*. Ventral aspect of the gasbladder capsule and Weberian ossicles of *Protomyzon whiteheadi* (Vaillant).

,, 9*c*. Front view of the gasbladder capsule and Weberian ossicles of *Pseudogastromyzon fasciatus* (Sauvage).

,, 9*d*. The caudal fin skeleton of *Pseudogastromyzon fasciatus* (Sauvage); fin rays are not shown.

,, 9*e*. Ventral view of the basipterygia of *Glaniopsis hanitshi* Boulenger.

first (or fifth in the series) articulates and the next (or sixth) is fused with the base of the last centrum. In these forms therefore, there are two fused and four articulating hypurals. In *Pseudogastromyzon* (fig. 9*d*), however, the last two (fifth and sixth) have united together into a single hypural (*hy5*) which, of course, is fused with the base of the centrum of the last vertebra. While the hypurals and

epurals of the penultimate vertebra are normal, in the vertebra preceding this, the elements are forked in *Pseudogastromyzon*, a feature also shared by *Vanmanenia*.

In *Nemachilus* (Cobitidae), the number of hypurals on the posterior aspect of the urostyle is seven with a single radial anteriorly to it; in the Homalopteridae (Ramaswami, 1952*c*, in press), the hypurals on the posterior aspect of the urostyle varies from 6 to 8.

The basipterygia.—The nature of the basipterygium is of great systematic importance (Fang, 1930; Hora, 1932). While the basipterygia of a large number of Gastromyzonids have been described, those of *Glaniopsis* are unknown. *Glaniopsis* also shows the two basipterygia (fig. 9*e bpr*, *bpl*) united mesially as in the Gastromyzonidae and the Homalopteridae. Each basipterygium, however, shows anteriorly a lateral horn (*lh*) characteristic of the Gastromyzonidae; but the forking to produce the horn is narrow as in the Cyprinidae, though, however, in the latter the two basipterygia do not approximate mesially. In the Homalopteridae generally, the horns are absent but a lateral foramen is noticed at the region the modified rib comes in contact with it (Hora, 1932). In *Glaniopsis*, there is a deep depression (fig. 9*e dep*) noticed starting from the anteromesial edge and progressing laterally posteriorly. There are also a number of symmetrically placed foramina in the two basipterygia. Thus in the basipterygia possessing lateral horns, *Glaniopsis* resembles the other Gastromyzonid genera studied.

Discussion.

In describing the Homalopteridae (including the Gastromyzonidae) Hora (1932) noted that the two genera *Octonema* and *Glaniopsis* were Cobitids and they belonged to the genus *Nemachilus*. Particularly with regard to *Glaniopsis*, he recorded that 'Their almost terminal mouth, the plain and fleshy lips, the long barbels and the beaked condition of the jaws especially the upper one, indicate close relationship between *Glaniopsis* and *Nemachilus*. . . In my opinion *Glaniopsis* should be placed in the Cobitidae among *Nemachilus*-group (without suborbital spine)....' I have examined the skeletal characters of *Glaniopsis*, and *Octonema* was not available to me. Undoubtedly the Bornean *Glaniopsis* shows a large number of Nemachiline features but it also exhibits a few characteristic Gastromyzonid features which cannot, however, be overlooked. The Nemachiline features exhibited by *Glaniopsis* are as follows:

The possession of
1. a narrow supraethmoid,
2. a pair of prepalatines,
3. poorly developed lateral ethmoids,
4. small lacrimojugal,
5. very small subtemporal fossa,
6. a projecting preopercular process,
7. a posteriorly directed opercular process of the hyomandibula,
8. a prominent ridge on the metapterygoid,
9. a divided gasbladder enclosed in a bony capsule with the Weberian ossicles associated with each.

The features in which *Glaniopsis* differs from *Nemachilus* may now be recounted.

In *Glaniopsis*
1. the pharyngeal process is large,
2. the exoccipital fenestrae are absent and the exoccipitals do not roof the foramen magnum,
3. the posterior process of the quadrate is short and broad,

4. the hyomandibula shows a flat facet for articulation with the pterotic,
5. the orbitosphenoids are double,
6. an independent sensory canal bone is absent in front of the preopercular,
7. the posterior commissure connecting the two parts of the gasbladder does not show a posterior gasbladder,
8. the basipterygia are mesially united and show lateral horns.

It is clear that in a number of internal (as enumerated above by me) and external characters [as stated by Hora (1932)], *Glaniopsis* resembles *Nemachilus*. But in possessing independent sensory canal ossicles in the supraorbital, suborbital, temporal and supraoccipital regions and in not having the exoccipital fenestrae *Glaniopsis* stands apart from the Cobitids. In the latter feature, however, it resembles the Homalopteridae and the Gastromyzonidae. Of these two families, it is more Gastromyzonid because of the possession of a shallow subtemporal fossa, of a hyomandibula showing a flat pterotic articular facet, of a large pharyngeal process, of dorsal gillrakers on the branchial arches and of the mesially united basipterygia showing no lateral foramen. It is evident in view of the above observations that *Glaniopsis*, though showing a number of internal and external Nemachiline features, has progressed towards the Gastromyzonidae. It could, therefore, be treated as a member of the Gastromyzonidae[1]; it may not be incorrect to treat *Glaniopsis* as the type of a group (or association of Fang) under the Gastromyzonidae in addition to the *Gastromyzon*- and *Crossostoma*-groups created by Fang (1935). It is very likely that a loachlike ancestral Glaniopsid adapted itself to a life in torrential waters and developed Gastromyzonid features ; and such an ancestor was the progenitor of the modern Gastromyzonids in Borneo.

Since *Glaniopsis* is restricted to Borneo and is not found on the mainland, it stands to reason to assume that a separate ancestral type gave rise to the Chinese forms and Hora (1951) has come to the conclusion that the mainland and the Bornean forms had no geographical continuity during their evolutionary history. Thus the Chinese and Bornean forms have evolved independently and curiously many parallel features are seen among them. The Bornean *Protomyzon* and the Chinese *Vanmanenia* resemble each other: the moderately large lacrimojugal-rostral, the large dorsal premaxillary process of the maxilla, the narrow supra-ethmoid portion, the absence of the prepalatine, the large lateral ethmoid and the occurrence of two preethmoids are all common features. Only in *Protomyzon* the supraorbital and temporal canals are independent of the skull bones resembling thereby *Glaniopsis*. Hora (*in. litt.*) informs me that there are resemblances between *Glaniopsis* and *Protomyzon* and the two could be connected by an intermediate form like *Parhomaloptera* which, unfortunately, I have not been able to secure for examination. Except for the points mentioned above, the skull of *Glaniopsis* differs widely from that of *Protomyzon*. However, in showing a large lacrimojugal-rostral, a premaxilla with a very large lateral limb and in the disposition of its dorsal process in front of the rostral and in the possession of a small supraorbital, the Bornean *Gastromyzon* (Ramaswami, 1948) is unique and must have evolved

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[1] In a recent article in the *Records of the Indian Museum* (Vol. 48, pt. 2, pp. 85–88, 1950, Hora and Jayaram have re-described *Glaniopsis* and have discussed from a purely taxonomic point of view. They have concluded that:

'In its general form and structure, *Glaniopsis* differs little from *Nemachilus* and allied Cobitid genera, but in its greatly depressed head and anterior part of the body, and the division of the pectoral fin into an adhesive outer portion and a vibrating inner portion, it shows an advance over the Cobitidae and approaches the Gastromyzonidae. *Glaniopsis* could thus be considered as a less specialised genus in the Gastromyzonid group of fishes.'

independently of the other Bornean genera. Judging by the characters exhibited by *Gastromyzon*, it would be incorrect to imagine that a form like that could have descended from a Glaniopsid-like ancestor.

On the mainland also, while *Beaufortia* and *Pseudogastromyzon* show similarities in the nature of lacrimojugal-rostral (comparable with the big one in *Gastromyzon*), in the large supraethmoid, in the possession of a frontoparietal fossa, of a supratemporal which is not triradiate and of a rostral which is in contact with the supraethmoid process, *Crossostoma* shows a comparatively small lacrimojugal-rostral (more like that in *Vanmanenia* and the Bornean *Protomyzon*), a small rostral and a pair of prepalatines and a very broad prevomer. It is difficult to derive *Crossostoma* from any mainland or Bornean form examined since in none of these a prepalatine is developed; it is only in the present-day *Glaniopsis* that the prepalatines are noticed and, therefore, it is likely that on the mainland also a Crossostoma-like ancestor gave rise to the existing forms. Hora (*in. litt.*) writes that *Crossostoma* shows certain resemblances to *Vanmanenia* and an evolutionary series like *Vanmanenia—Preformosania—Formosania—Crossostoma* could be established. However, *Vanmanenia* and *Crossostoma* resemble each other as already said, only in the relatively small lacrimojugal-rostral. According to me, as our knowledge of the Gastromyzonid skeleton stands today, three trends of evolution seem to have taken place on the mainland from an ancestral Crossostomid: one resulted in the present-day *Crossostoma* with the prepalatines; the other two lines branched off before the appearance of the prepalatines in the ancestral Crossostomid and gave rise to *Vanmanenia* on the one hand and on the other to *Beaufortia* and *Pseudogastromyzon*.

Thus there appears to be two independent lines of evolution of the Gastromyzonid forms; one on the mainland and the other in Borneo, the evolution therefore being diphyletic and as already remarked, most of these forms show parallel features in their organization.

It may not be out of place here to mention that there are four important features in which the skeleton of the examined genera of the Gastromyzonidae differs from that of the Homalopteridae. The Homalopterid subtemporal fossa is very large while in the Gastromyzonidae, it is very shallow and the pharyngeal process is also very well developed in the latter family. While in some Gastromyzonidae, the hyomandibula shows a flat articular facet for articulation with the pterotic region, in no Homalopterid is such a feature noticed. The basipterygium of the Gastromyzonidae shows the lateral horn and lacks the characteristic homalopterid lateral foramen. The hyobranchial apparatus of the Gastromyzonidae exhibit the dorsal gillrakers, completely wanting in the Homalopteridae.

Summary.

1. The Bornean *Glaniopsis* exhibits a number of Nemachiline features, *viz.*, narrow supraethmoid, prepalatines, poorly developed ethmoid, small subtemporal fossae and divided gasbladder enclosed in bony case. But it differs from it in not having united orbitosphenoids, in the absence of exoccipital fenestrae and in possessing the mesially united basipterygoids. Therefore, it cannot be considered a Nemachiline Cobitid. It is more Gastromyzonid in showing shallow subtemporal fossae, dorsal gillrakers on the branchial arches and the mesially united basipterygoids with no lateral foramina. It is argued that a Glaniopsid-like ancestor may have given rise to the Bornean Gastromyzonid genera.

2. Since *Glaniopsis* is restricted to Borneo, it is likely that some other form must have given rise to the Gastromyzonidae on the mainland of China. The mainland forms vary among themselves very much and they are a polyphyletic assemblage. It is argued, therefore, that an ancestral Crossostomid may have given rise to at least three branches; the first is represented by *Crossostoma*, the second by *Vanmanenia* and the third branch by *Beaufortia* and *Pseudogastromyzon*.

3. Two independent lines of evolution of the Gastromyzonidae have therefore taken place; one on the island of Borneo and the other on the mainland of China. It is known that there was no geographical continuity at any time between the two areas.

Acknowledgment.

I am deeply grateful to the Council of the National Institute of Sciences of India for the award of a senior fellowship. I am thankful to Dr. S. L. Hora, Director, Zoological Survey of India, Calcutta, for helping me with specimens, literature and also for the critical discussions I have had with him; I must also express my sincere thanks to Professor B. R. Seshachar for his numerous acts of kindnesses.

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Key to Abbreviations.

amy .. anterior myodome.
an .. angular.
ao .. passage for aortic branch.
apa .. articular facet of entopterygoid for palatine.
aq .. articular facet of the quadrate for lower jaw.
aup .. auricular process.
bc .. broken gasbladder capsule.
bo .. basioccipital.
bpl .. left basipterygium.
bpr .. right basipterygium.
cap .. gasbladder capsule.
cen .. fused centra.
cl .. claustrum.
co .. occipital condyle.
c1 .. first centrum.
c2 .. } penultimate centrum and
c3 .. } one behind it.
den .. dentary.
dep .. depression in the basipterygia.
dpm .. dorsal premaxillary process.
dr1 .. first pair of dorsal ribs.
eap .. entopterygoid articulation facet of palatine.
ecp .. ectopterygoid.
elp .. ethmoid limb of palatine.
eo .. exoccipital.
epi .. epiotic.
ept .. entopterygoid.
ep2 .. epural of the penultimate vertebra.
ep3 .. bifid epural.
et .. ethmoid.
ex24 .. expanded neural arches of second and fourth vertebrae.
far .. articular facet for the radials.
fp .. facet for the articulation of supracleithrum.
fpa .. facet of palatine for lateral prepalatine articulation.
fpf .. frontoparietal fontanel.
fr .. frontal.
fr' .. ventral aspect of frontal.
gap .. lateral opening in the gasbladder capsule.
hu2 .. hypural of penultimate vertebra.
hu3 .. hypural of vertebra in front of the penultimate.
hy .. hyomandibula.
hy1 .. } hypurals associated with uro-
hy5 .. } style and last centrum.
in .. independent sensory canal ossicle.
int .. intercalarium.
iop .. interopercular.
ios .. independent sensory canal ossicles on sphenotic.
iol .. interosseous ligament.
jf .. jugular foramen.
les .. lateral extrascapular.
let .. lateral ethmoid.
lgb .. lateral wall of gasbladder.
lh .. lateral horn.
lj .. lacrimojugal.
llm .. lateral limb of maxilla.
lpl .. lacrimojugal-rostral process of palatine.
lr .. lacrimojugal-rostral.
l1 .. ligament between dorsal process of maxilla and palatine.
l2 .. ligament between rostral process of maxilla and median rostral.
l3 .. ligament between median rostral and anterior process of ethmoid.
mco .. mandibular sensory canal ossicles.

mgb .. median portion of gas-bladder.
mp .. metapterygoid.
mr .. median rostral.
mr' .. posterior portion of median rostral.
n .. nasal.
na2 .. fused second and third neural arches.
oa .. articular process of operculum.
ocl .. outline of claustrum.
of .. optic foramen.
ohy .. outline of orifice in hyomandibula.
on .. outline of nasal.
oop .. outline of opercular.
op .. opercular.
ope .. orifice in the second preethmoid.
ophy .. opercular process of hyomandibula.
opl .. outline of palatine.
opop .. outline of preopercular.
opr .. orifice in prootic.
op2 .. outline of second preethmoid.
os .. orbitosphenoid.
oso .. outline of subopercular.
os7 .. outline of so7.
otr .. orifice for the tripus.
p .. anterior process of ethmoid.
pa .. parietal.
pal .. palatine.
pas .. parasphenoid.
pet .. first preethmoid.
pe2 .. second preethmoid.
ph .. facet for hyomandibular articulation.
php .. pharyngeal process.
phy .. facet of hyomandibula for articulation with pterotic.
phy' .. flat facet of hyomandibula.
pll .. process of maxilla for adductor mandibular muscle ligament.
pls .. pleurosphenoid.
pmp .. posterior process of metapterygoid.
pmy .. posterior myodome.
pmx .. premaxilla.
pop .. preopercular.
ppa .. lateral prepalatine.
ppa' .. median prepalatine.
ppm .. articular facet of maxilla with prepalatine.
ppr .. process of operculum.
pq .. posterior process of quadrate.
pr .. process of the hyomandibula
pt .. posttemporal.
pte .. pterotic.
pv .. prevomer.
q .. quadrate.
qa .. articular facet in the angular for quadrate.
r .. radial.
ra .. retroarticular.
ri .. ridge on the metapterygoid.
ri' .. ridge on the entopterygoid.
rpm .. rostral process of maxilla.
rpp .. rostral process of premaxilla.
sa .. supraangular.
sb .. sesamoid bone.
sc .. sensory canal ossicle.
sc' .. mesial sensory canal.
sca .. scaphium.
se .. supraethmoid.
sh .. sphenotic facet for hyomandibular articulation.
shy .. facet of hyomandibula for articulation with sphenotic.
sn4 .. orifice for fourth spinal nerve.
so .. supraoccipital.
sop .. subopercular.
so1–so9 .. sensory canal ossicles 1–9.
sp .. sphenotic.
spr .. sphenotic process.
ste .. supratemporal.
stf .. subtemporal fossa.
sui .. supraoccipital sensory canal.
suo1–suo4 .. supraorbital sensory canal ossicles 1–4.
sup .. supraoccipital process.
sy .. symplectic.
sym .. symphysis meckelii.
tc .. temporal canal.
tf .. trigeminofacialis opening.
trc .. transverse canal.
tri .. tripus.
uc .. ultimate centrum.
ur .. urostyle.
v4 .. postzygapophysial part of fourth vertebra.

A NOTE ON PHYSICAL CHARACTERISTICS OF RIVER SAND.

By HARSH VARDHAN, *Defence Science Organisation, New Delhi.*

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ABSTRACT.

A few experiments with Jamna sand available at Delhi are described and discussed. These deal with sieve analysis, variation in dry density with compactive effort and moisture content, and the variations in shear-strength. It has been found that Jamna sand resembles to a fair degree the Daytona beach and the Port Said beach sands in the grain size distribution. The bulk density of dry sand increases with compaction to a maximum and then stays constant. Further increase in compactive effort is effective only in breaking the sand grains. Addition of moisture to sand, on the other hand, lowers the dry density at first rapidly and then slowly. For clean uniform sand there is no optimum moisture content at which the compaction be maximum as is the case with other soils. The shear-strength value, however, shows a definite maximum for a particular moisture content. This is so because of the cohesion which mainly contributes to the shear-strength and becomes most effective at the optimum moisture content.

The samples of sand were taken at random from the sand heaps collected by the contractors for constructional purposes, and may be regarded as fairly representative.

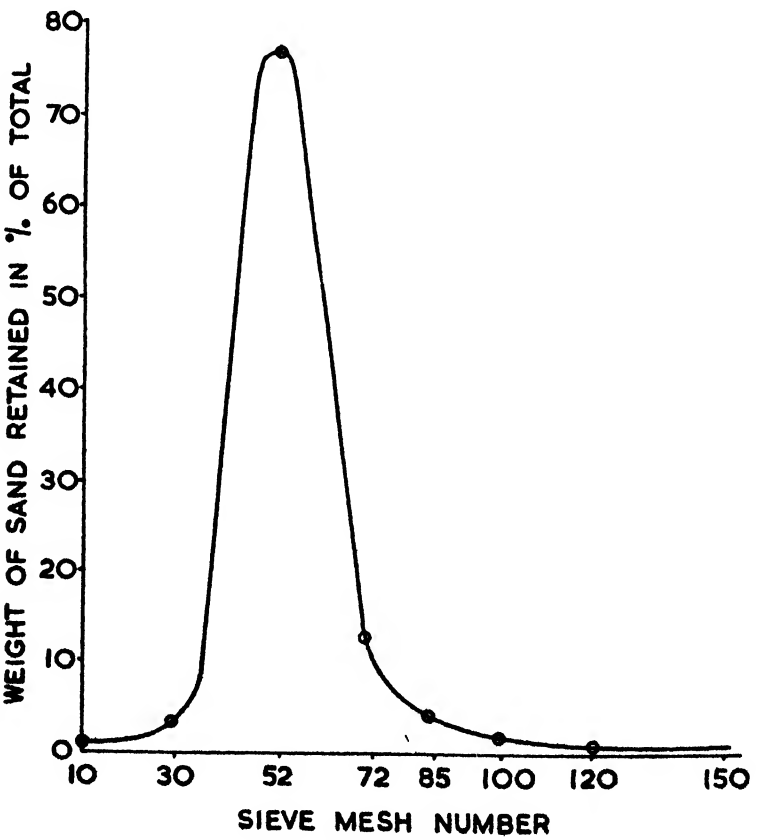

FIG. 1*a*.

The sieve analysis is graphically represented in fig. 1. The curve of fig. 1*a* gives the amount of sand by weight that is retained on a sieve of a given mesh number but has all passed through a sieve of the lower mesh number. Fig. 1*b* gives the weight of sand all passing through a corresponding sieve, in terms of percentage fraction of the total weight. Both the curves are based on values obtained without separating and accounting for the mica flakes present in the sand. The quantity of mica by weight is though quite small, its presence may give some elastic properties to the sand mass and influence compaction and shear-strength

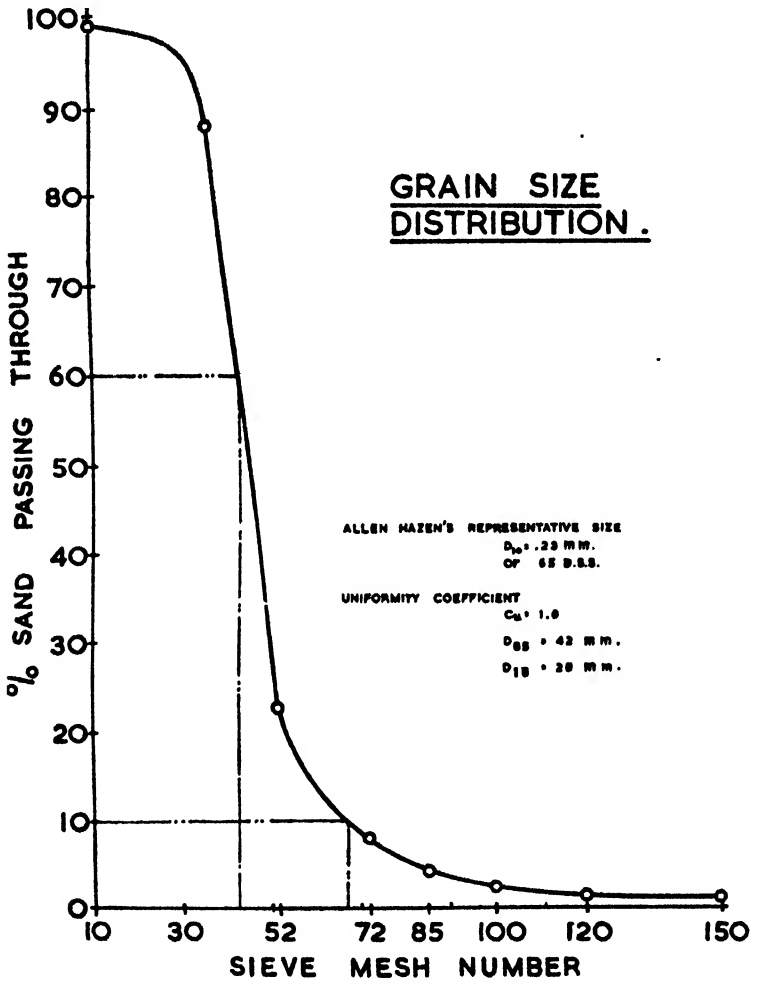

FIG. 1*b*.

etc. It is seen from the curves that the sand is medium and fine; it mostly consists of particles of sizes about ·26 mm. The Allen Hazen's most representative size, commonly called the Effective Size D_{10}, is ·23 mm. It is the maximum diameter of the smallest 10% fraction. The Uniformity Coefficient C_u, which is the ratio of the maximum size of the smallest 60% (D_{60}) to the effective size (D_{10}), is 1·8. It is, therefore, a fairly uniform sand. The D_{15} and D_{85} are ·28 and ·42 mm. respectively and the piping factors can be determined according to as the sand is to be used as a filtering or as the retained material. A grain size distribution curve, each for the Daytona beach and Port Said beach sands, is reproduced (Tsche-

botarioff, 1951) for comparison in fig. 2. The grain size distribution of Jamna sand is almost similar to them both, but otherwise it consists of coarser particles.

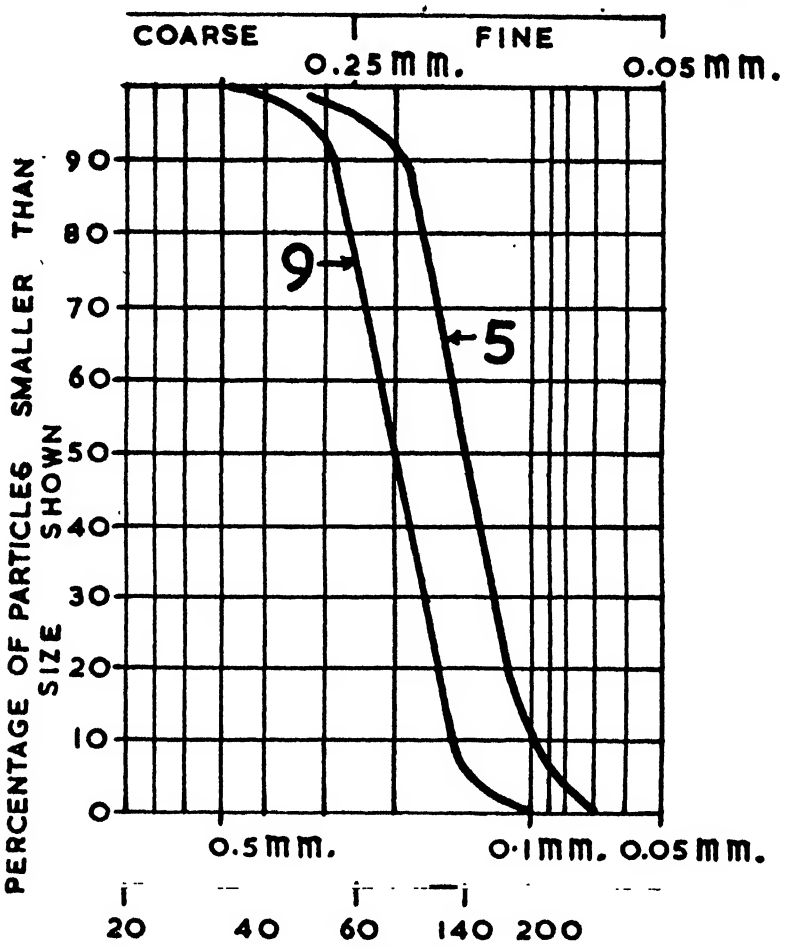

FIG. 2.

The sand is grey-black in colour if looked at ordinarily in aggregate, but the various sieved fractions exhibit a change in colour. The coarser fractions show a darker shade than the finer fractions. On examining under a microscope it is found to consist of clear transparent and opalescent white particles mixed with black, grey, yellow, brown and mauve particles mostly opaque. The black, grey and brown grains are comparatively more in number than grains of other colours. The number of coloured grains is relatively more in coarser fractions. The finer fractions consist mostly of transparent grains. A rough estimate of relative abundance of uncoloured and coloured grains is given in Table I. The smaller count of coloured particles in finer fractions leads to the conclusion that the coloured material is stronger than the uncoloured. The grains are all quite irregular in shape. A fair fraction of the flake mica is retained on Nos. 30 and 52 mesh B.S.S. sieves. The specific gravity of the sand is 2·68. The angle of repose for different fractions varies from 35° to 37°.

Compaction of the sand is obtained by means of a hammer of 6 lb. falling through a vertical distance of one foot on sand placed in a cylindrical container which is made in two parts as usual; the upper part being detachable in the form of a ring from the lower actual container. The latter has a capacity of 1/120 ft.^{3}.

TABLE I.

Mesh No. of sieve retaining the sand.	Percentage of grains of various colours.			
	Clear transparent.	Opalescent.	Lightly coloured: brownish, yellowish, greenish.	Dark coloured: grey, black, brown, red.
30	45	10	15	30
52	60	8	12	20
72	68	6	12	14
85	74	5	8	13

The diameter of the container was only slightly more than that of the hammer to allow clearance for free movement. The hammer, therefore, strikes the whole surface of the sand each time thus giving more uniform compaction than is obtained by the conventional design. Each stroke of the hammer delivers an energy of 6 foot pounds.

The curves in fig. 3 represent the variation of bulk density of the different fractions of Jamna sand against compaction. Almost maximum compaction is

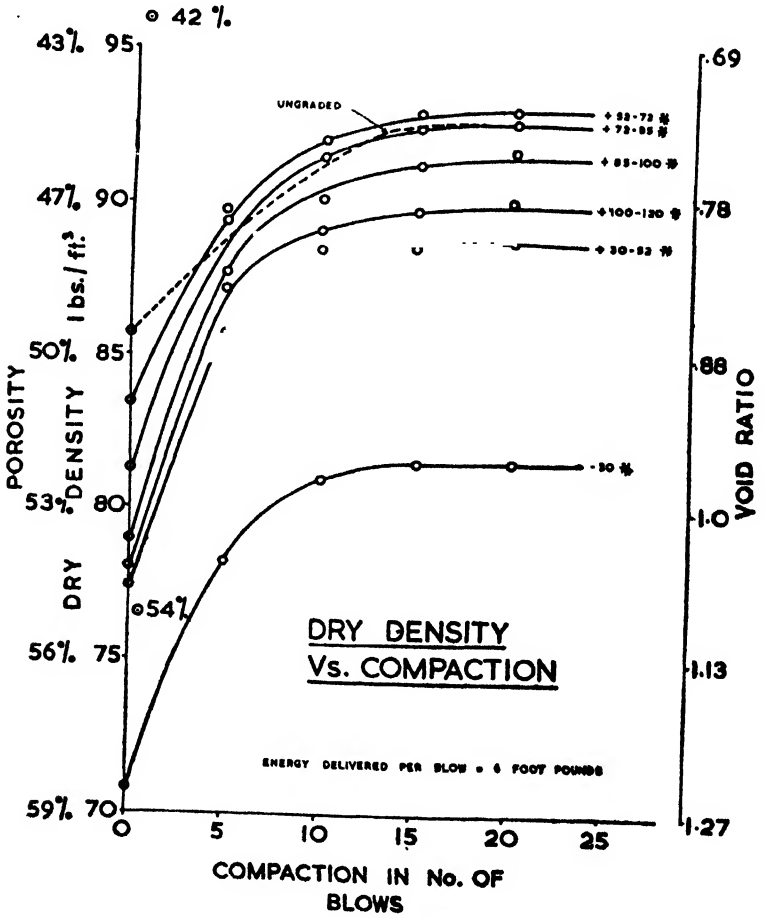

FIG. 3.

reached at 15 strokes of the hammer. More hammering does not appreciably increase the bulk density. The maximum density obtained is 92·5 lb./ft.^{3}. The actual solid density, as calculated from the specific gravity value of 2·7, comes out to be 170 lb./ft.^{3} nearly. The value of 92·5 lb./ft.^{3} seems to be quite low and may partly be due to arching of sand grains in the container. The maximum and minimum bulk density for the whole dry sand is 96 and 78 lb./ft.^{3} and corresponds to a porosity of 42% to 54% respectively. J. Kolbuzewski (1950) has shown that porosity varies from 36% to 47% for Leighton Buzzard sand under different conditions of deposition. The porosity of well-arranged ideal aggregates of spheres varies from 25·95% to 47·64%. Porosities of compacted aggregates of spheres obtained by Fraser (1935) exceeded the calculated value of 25·95% by about 50%. The fact that the porosity of compacted spheres far exceeds the ideal minimum porosity suggests that most compact possible arrangements may never be obtained by ordinary compaction methods. Uniform loose sand and quick sand may have porosity as high as 45 to 48% (Baver, 1946). Pure quartz sand may weigh from 90 lb. to 105 lb. when dry.

In fig. 4 are given curves for dry density values plotted against the moisture content at two different compactions of 5 blows and 20 blows each. The dry density is maximum for sand when it is dry but becomes less, rapidly, as it is moistened and then remains more or less constant as the moisture is increased

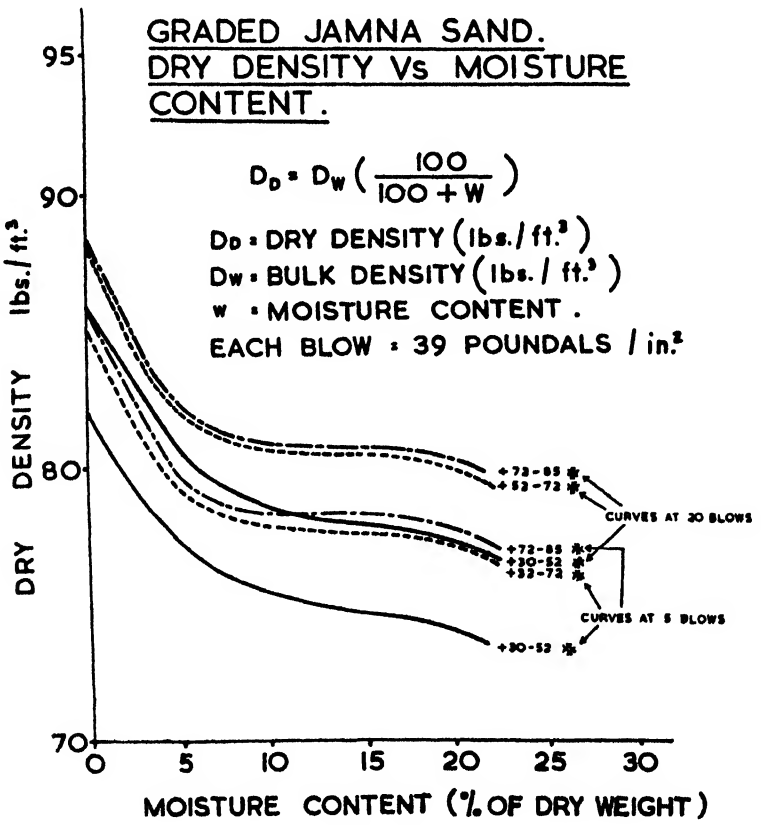

FIG. 4.

till the saturation limit is reached. This fall in the dry density value may be because of the 'bulking' of the slightly moist sand which partly persists even after compaction. The increase in volume that exists even after compaction is because of the arching of sand grains which were thrown into favourable positions

to do so during bulking. Such a condition exists till saturation is reached; the sand grains float and further compaction is not possible. According to Tschebotarioff (1951), 'the water content of a relatively clean sand has practically no influence on its dry density as produced by the same compactive effort. A slight addition of silt or clay to sand improves its grading and permits the development of greater density for the same compactive effort. The effect of moisture during moulding is then considerable. So long as the amount of silt and clay added is only small and no greater than is needed to partially fill the voids of sand.....the maximum density will increase, and the optimum moisture content will decrease as compared with cleaner sand and the same compactive effort.'

A comparison of the two compactive efforts in the present investigations with two other tests is given in Table II. The actual density values in the two cases obviously differ but the order of increase in dry density against the increase in compactive energy is almost the same. It is also to be noted that an increase in

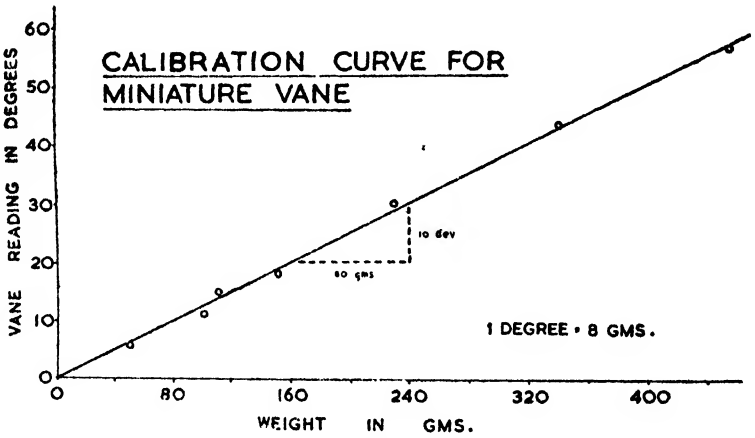

FIG. 5.

TABLE II.

Type of compaction.	Compactive effort in ft./lbs. per ft.^{3}	Dry density obtained lb./ft.^{3}	Moisture content % of dry wt.
15 blows—proctor test ..	7,400	108	12
Standard proctor test ..	12,300	110	12
Authors 5 blows	3,250	78	12
Authors 20 blows	13,000	82	12

compactive effort on clean sand merely raises the curve towards higher dry density value without appreciably changing its general shape.

The variation in shear strength with varying moisture content is shown by the curves of fig. 6. The shear strength values are recorded by means of a miniature vane made according to the pattern described by Sherret and Evans (1948). The vane is first calibrated by replacing it with a drum of diameter equal to the total span of the vane. The drum carries a pin passing through it along one of its diameters and projecting a little out of the surface at both ends. A thread fastened to the pin and around the drum passes over two ball-bearings at the two sides and carries at each of its two ends featherweight pans for loading. This way a rotating couple can be exerted on the drum and can be evaluated without requiring

correction for friction and gravity, etc. The calibration curve for the spring used is given in fig. 5. The slope of it gives the total torque on the spring per degree reading on the disc. The drum is replaced by the vane. It is inserted in the soil to same depth each time and the readings are recorded when the graduated disc has started moving with the pointer. Shear strength values are calculated from these readings and the vane dimensions.

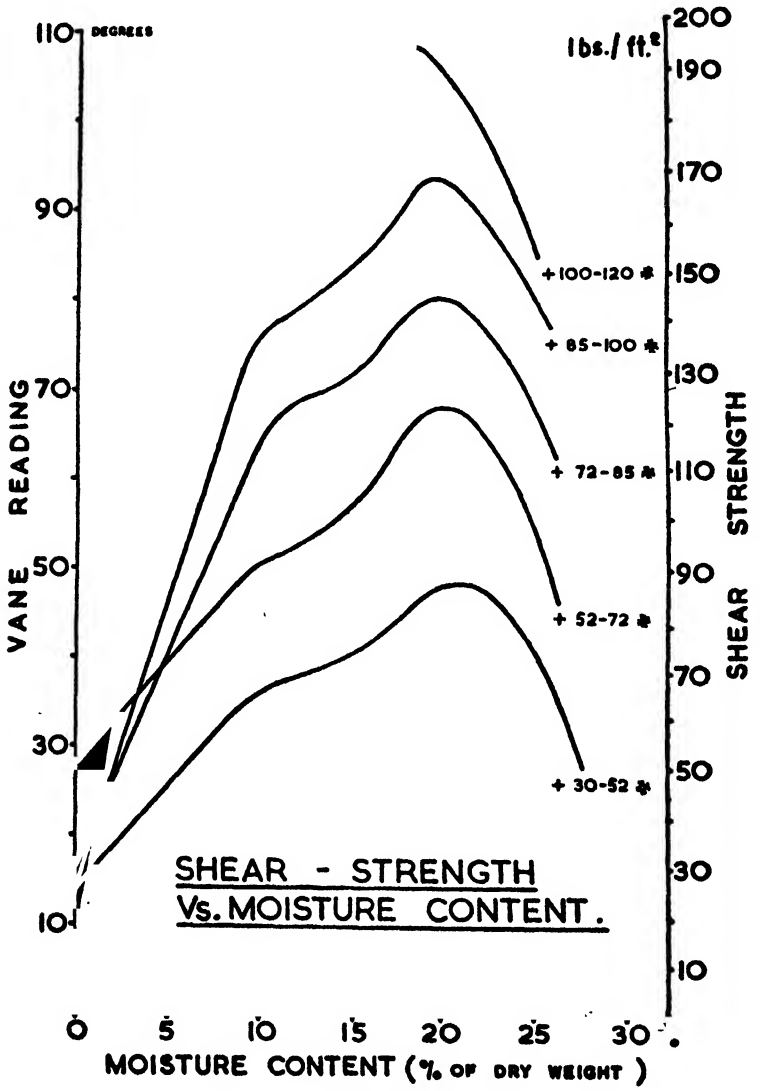

FIG. 6.

The hammer described before is used for compaction. Each blow of the hammer corresponds to an energy of 6 ft. lb., which, taking the volume of the soil to be a little more than 1/120 ft.^{3} is nearly 650 ft. lb./ft.^{3} of the soil. A compactive effort of 5 blows used for these curves, therefore, is equivalent to 3,250 ft. lb./ft.^{3}. The following points are noticed from these curves:—

(i) The shear strength is lowest for dry sand. It rises as the moisture content is increased up to a certain value called the 'Optimum moisture content' and then falls again with further increase of water content.

(ii) The maximum value of shear strength increases with decrease in grain size.

(iii) The rate of increase of shear strength becomes less between 10% to 15% moisture content.

The increase in shear strength in noncohesive soils like sand can be attributed to the presence of moisture in the sand mass. Thin layers of water first envelope the individual grains sticking strongly to the enclosed solid surface. This binding between water and solid surface is called Adhesion. The adhesive force of the soil for water varies from 0 in a saturated soil to 2,50,000 (Breazeale and Grider, 1934) or more atmospheres in a nearly dry soil. In an ordinary air dried soil the pull is about 1,000 atmospheres. The quantity of moisture in such a case is so small that it does not contribute to cohesion. When moist grains come close together the water envelopes bind with each other at the points of contact and develop in the soil mass what is termed cohesion. As moisture increases more grains are enveloped resulting in an increase in over-all cohesion till the water becomes excessive. Also as the sand grains become smaller in size the number per unit volume increases and so does the number of the binding contacts. It has been found that the cohesion varies inversely as the size of the particle, i.e. $C \propto \frac{T}{d}$ (Baver, 1946) where T is the surface tension of water and d the diameter of grains. $C \times d$ is therefore a constant. Table III gives the values of $C \times d$ for each of the curves of fig. 6 and shows that the product is almost constant. This also affords

TABLE III.

Shear strength or cohesion C.	Grain size d.	$\frac{T}{C}$ in lb./ft.^{3} $\times d$ in mms.
195 lbs./ft.^{3}	·14 mm.	27·3
170 ,,	·16 ,,	27·2
145 ,,	·19 ,,	27·6
124 ,,	·23 ,,	28·5
87 ,,	·33 ,,	28·7

a check on the applicability of the vane to noncohesionless soils. The values of $C \times d$ are a little more for bigger grain sizes. This may be attributed to increased interlocking due to less similarity to spherical shapes.

ACKNOWLEDGMENT.

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ON THE CUTANEOUS SENSE-ORGANS OF A COMMON SILUROID FISH, *RITA RITA* (HAMILTON).

By IFTIKHAR HAMID BHATTI, *M.Sc.*

(Communicated by Dr. Hamid Khan Bhatti, Ph.D. (Cantab), F.N.I.)

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Cutaneous sense-organs of Teleostean fishes exhibit many features of interest, both as regards morphology and histology, and have been dealt with by a number of workers. Very little, however, is known of the details of such organs in the Teleostean fishes of the Indo-Pakistan sub-continent. Bhatti (1938) first described the cutaneous sense-organs in an Indian Siluroid fish, *Rita rita* (Hamilton). Islam (1950, 1951) and Bhatti and Islam (1950) described similar organs in a number of fishes studied by them. Recently Bimla Bhatia (1950) gave an account of such organs in *Glyptothorax telchitta* (Hamilton). Her account differs greatly from that of the previous authors. It has, therefore, been considered necessary to undertake full investigation of the cutaneous sense-organs in one of our common Siluroid fish, *Rita rita* (Hamilton), so as to study the frequency and distribution of these sense-organs on different parts of the skin of this fish.

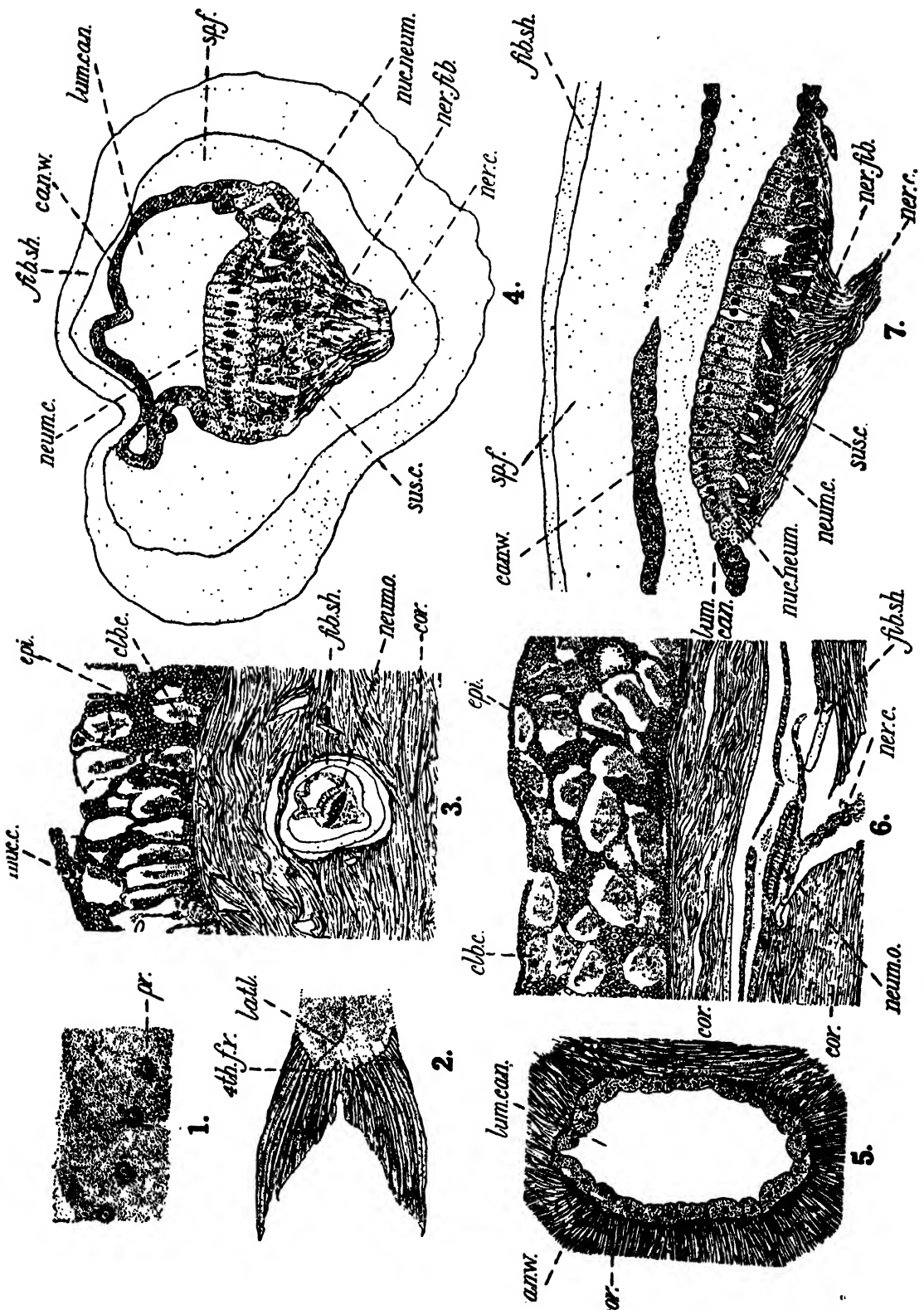
MATERIAL AND TECHNIQUE.

The study of the cutaneous sense-organs of *Rita rita* has been made by cutting serial sections of the skin from various regions of the body, i.e., head, lateral line and barbels. The material was fixed in Bouin's fluid and sections were cut to the thickness of 6 to 8μ. The various stains used were Delafield haemotoxylin, counter-stained with eosin, and orange G., and Mann's methylene blue with eosin. Mallory's triple stain was used for some sections of the mandibular barbel to confirm the presence of connective tissue in the interior of the barbel. Cajal's silver nitrate reducing method was tried, but without good results, for the detection of free nerve endings in the skin and nerve distribution to the various cutaneous sense-organs.

HISTORICAL.

Leydig (1851) first described the cutaneous sense-organs in *Esox*, *Gasterosteus* and *Lota*, but made no distinction between the organs of the lateral line and the beaker-shaped sense-organs or end buds. Schulze (1867) for the first time pointed out the difference in the form of the sensory cells in these two kinds of sense-organs. Merkel (1880) drew sharp distinction between the two classes of cutaneous sense-organs, namely, the beaker-shaped sense-organs, which he termed 'End knopsen' (end buds), and the others he called 'Nerven hugel' (nerve hillocks). This distinction between the two kinds of the cutaneous sense-organs has been maintained by the subsequent authors.

Walter (1928) includes under the cutaneous sense-organs a variety of receptors. In Teleostean fishes, there are, firstly, *rheoreceptors* or current receptors, namely, lateral line sense-organs and nerve hillocks, which aid the animal in orientation to the flowing water, and secondly, *gustoreceptors* or end buds or taste buds with gustatory function.



FIGS. 1–7.—See foot of next page for explanation.

A. *Rheoreceptors.*

1. *Lateral line sense-organs.*—In *Rita rita* (Hamilton), the lateral line extends in a straight line along the sides of the body and is cutaneous, while in the region of the head it lies beneath the skin and becomes subcutaneous. It is a closed canal opening to the exterior by a number of small pores at regular intervals (Fig. 1, *pr.*). The distance between the two adjacent pores is 3·5 mm. in the adult, i.e., there are seven pores to every 2·1 cm. area. All the pores are single, sometimes double, and are arranged in a single row. The lateral line canal starts (Fig. 2) as a fine tube from the dorsal part of the hypochordal lobe of the caudal fin. In fishes measuring 31·5 cm., 41·5 cm. and 52 cm. in length, the lateral line starts from the base of 4th (Fig. 2, *4th f.r.*), 8th and 6th complete fin ray respectively. Curiously enough, such condition has been described mainly in connection with fishes with heterocercal tail (Collinge, 1894; Smith, 1936), while in Actinopterygii, where the tail is homocercal, the commencement of the lateral line is described at the base of the caudal fin (Smith, 1936).

Histology.—In *Rita rita*, a transverse section of the skin passing through the lateral line shows the canal lying in the middle of the corium between the fibrous layers (Fig. 3) and not between the epidermis and the stratified fibrous layer as described by Wright (1884) in *Amiurus*. Brockelbank (1925), however, described in *Amiurus nebulosus* a similar location of the lateral line as found in *Rita rita*. The wall of the lateral line canal (Fig. 5, *can.w.*) is generally composed of a single row of cells and not double as described by Brockelbank (1925) in *Amiurus*. In its interior, the lateral line contains a large number of sense-organs—the neuromasts—(Fig. 3, *neum.o.*), which are placed in a metameric fashion, their number corresponding to the number of pores present on each side. The neuromasts are sharply marked off from the epithelium of the canal, each of them occupies nearly half of the circumference of the canal (Figs. 3 and 4), and may be four times as thick as the epithelial wall of the canal. At the exact location of each neuromast, a tough fibrous investment of connective tissue encircles the organ (Figs. 3 and 4, *fib.sh.*). This sheath corresponds to 'osseous substance' of Wright (1884) in *Amiurus*. Wright (1884) found no bone corpuscles in the 'osseous wall' of the canal as had been described by Leydig (1879). The corpuscles present in *Amiurus*, according to Wright (1884), were neither of bone nor of cartilage, though they were similar to connective tissue corpuscles. Later, Brockelbank (1925) described the investment of the neuromast in *Amiurus nebulosus* as a fibrous connective tissue, similar to one present in *Rita rita*. The lateral line canal is, thus, supported by a discontinuous sheath of fibrous tissue present only at the location of the neuromasts. The number of these sheaths corresponds to the number of the neuromasts in the canal. The sheath is considered to be a protecting element for the contents of the canal and is separated from the neuromast by an intervening space (Fig. 4, *sp.f.*). The radiating strands of the connective tissue of the corium adjoining the canal

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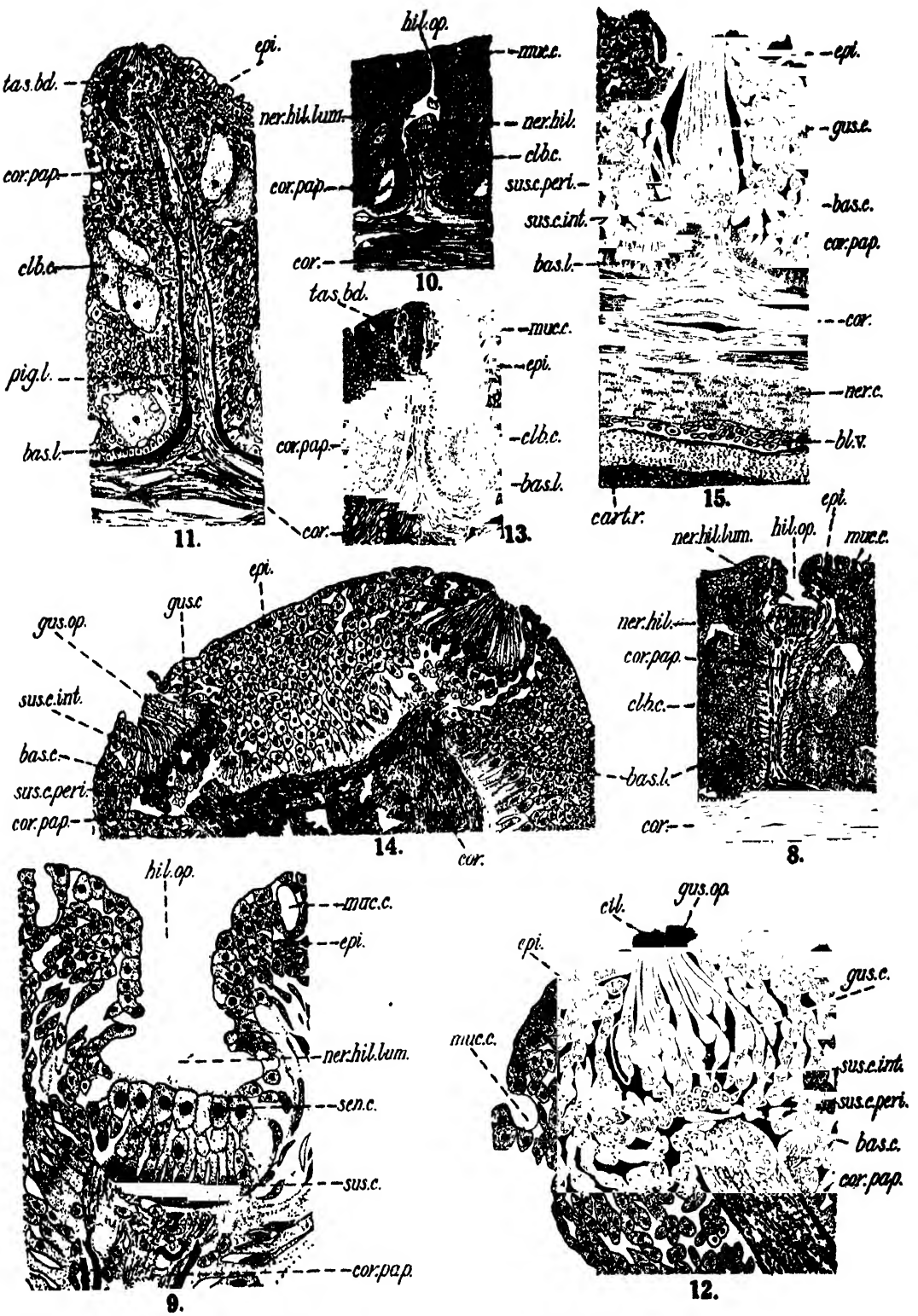
Explanation of Figs. 1–7, p. 548.

FIG. 1. Skin of the lateral line region showing lateral line pores. ×2.
FIG. 2. Caudal fin, showing commencement of lateral line. ×$\frac{1}{2}$.
FIG. 3. T.S. of skin, showing transverse section of lateral line. ×50.
FIG. 4. T.S. of lateral line canal. ×295.
FIG. 5. T.S. of lateral line canal, between the two neuromasts region. ×345.
FIG. 6. L.S. of skin, showing longitudinal section of lateral line. ×50.
FIG. 7. L.S. of lateral line canal. ×295.

can.w., wall of lateral line canal; *clb.c.*, club cell; *cor.*, corium; *epi.*, epidermis; *fib.sh.*, fibrous sheath; *lat.l.*, lateral line; *lum.can.*, lumen of lateral line canal; *muc.c.*, mucous cell; *ner.c.*, nerve cord; *ner.fib.*, nerve fibres; *neum.c.*, neuromast cell; *neum.o.*, neuromast organ; *nuc.neum.*, nucleus of neuromast cell; *pr.*, pore of lateral line; *sp.f.*, space between fibrous sheath and neuromast organ; *sus.c.*, sustentacular cell; *4th.f.r.*, fourth complete caudal fin ray.



FIGS. 8–15.—See foot of next page for explanation.

remain in close contact with the exterior of the sheath. In the region where the neuromasts are absent, the connective tissue fibres of the corium are closely applied to the canal wall (Fig. 5), which, in this region, consists of a single layer of well-defined epithelial cells, while in the region of the neuromasts the wall may exhibit two or three layers of epithelial cells.

Each neuromast is composed of two kinds of cells: (i) neuromast or receptive (receptor) or sensory cells and (ii) sustentacular (supporting) cells.

(i) *Neuromast or receptive cells.*—The neuromast cells lie towards the lumen of the canal (Figs. 4 and 7, *neum.c.*) and are superficial. They are long and arranged in a single layer. Those found on the sides of the sense organ are small in size, while those present in the middle exhibit their full length. Each neuromast cell has a large nucleus in its upper half (Fig. 7, *nuc.neum.*) and not in the lower half as shown by Cole (1898) in *Gadus*. Previous authors, Wright (1884), Cole (1898), Johnson (1917), Brockelbank (1925) and Walter (1928), described free hair at the free ends of the neuromast cells in the fishes studied by them, projecting into the lumen of the canal and are said to keep the fluid in the canal in motion. Such hairs, however, have not been observed in the specimens of *Rita rita* studied.

(ii) *Sustentacular or supporting cells.*—They are more or less of the same number as the sensory cells (Figs. 4 and 7, *sus.c.*) and their nuclei are found in the deeper part of the cells near the base of the neuromast organ, as has also been described by Brockelbank (1925) in *Amiurus*. The supporting cells occupy greater part of the neuromast organ and are situated beneath the receptor cells. Cole (1898) described the sustentacular cells in *Gadus* as 'mucous cells' corresponding to the 'indifferent cells' described by Wright (1884) in *Amiurus*. Nerve fibres (Figs. 4 and 7, *ner.fib.*) end at the base of the sustentacular cells and no direct connection between the nerve and the receptor cells is observed.

2. *Nerve hillocks* or *scattered pit organs.*—The nerve hillocks or scattered pit organs in *Rita rita* are found all over the body and especially in large numbers over the head and at the sides of the lateral line canal. The pit organs have been described by the previous authors, Leydig (1851), Solger (1878), Wright (1884), Rauther (1907), Johnston (1908) and others, as accessory lateral line organs. In *Rita rita*, the structure of the nerve hillocks has previously been described by Bhatti (1938). Islam (1950*a*) made no mention of these organs in *Rita rita*.

Histology.—In a transverse section of the skin, these nerve hillocks (Fig. 8, *ner.hil.*) appear as flask-shaped organs situated on the papilla of the corium (*cor. pap.*) and do not rest directly upon the surface of the corium as described by Bhatti (1938) in Siluroid fishes studied by him. The corium papilla occupies a length of 272μ in the epidermis which is 400μ thick, the rest of the thickness, i.e. 128μ, is occupied by the nerve hillock, which is 80μ broad. The opening of the nerve hillock

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Explanation of Figs. 8–15, p. 550.

FIG. 8. T.S. of skin, head region, showing a nerve hillock. ×90.
FIG. 9. Section of a single nerve hillock. ×350.
FIG. 10. T.S. of dorsal lip, showing a nerve hillock. ×50.
FIG. 11. T.S. of skin, showing a single taste bud. ×100.
FIG. 12. Section of a single taste bud. ×375.
FIG. 13. T.S. of dorsal lip, showing taste buds. ×50.
FIG. 14. Part of the section of mandibular barbel, showing taste buds. ×345.
FIG. 15. Part of the section (longitudinal) of the nasal barbel, showing a single taste bud. ×345.

bas.c., basal cell; *bas.l.*, basal layer; *bl.v.*, blood vessel; *cart.r.*, cartilaginous rod; *cil.*, cilia; *clb.c.*, club cell; *cor.*, corium; *cor.pap.*, corium papilla; *epi.*, epidermis; *gus.c.*, gustatory cell; *gus.op.*, gustatory opening; *hil.op.*, nerve hillock opening; *muc.c.*, mucous cell; *ner.c.*, nerve cord; *ner.hil.*, nerve hillock; *ner.hil.lum.*, lumen of nerve hillock; *pig.l.*, pigment layer; *sen.c.*, sensory cell; *sus.c.*, sustentacular cell; *sus.c.int.*, internal sustentacular cell; *sus.c.peri.*, peripheral sustentacular cell; *tas.bd.*, taste bud.

to the exterior is 32μ in diameter, while the length of the neck of the flask-shaped hillock is 48μ. The neck in the region of the lip (Fig. 10) is very long and measures 120μ in length, while corium papilla is short.

Each nerve hillock, like the neuromast of the lateral line, contains two types of cells: (i) sensory or receptor cells and (ii) sustentacular or supporting cells, occupying an area of 48μ at the base of the hillock.

(i) *Sensory or receptor cells* (Fig. 9, *sen.c.*) form a single layer, like those of the lateral line canal organ cells, but their number in each hillock is very small. In structure, these sensory cells are similar to those described in neuromasts. They are pear-shaped, with their broad ends towards the cavity of the nerve hillock, and pointed ends directed downwards. Their number varies from six to eight, have acidophil contents and a large nucleus. Cilia or cirri, which are said to be present on their free ends (Rauther, 1907), have not been observed in the specimens of *Rita rita* studied.

(ii) *Sustentacular or supporting cells* (Fig. 9, *sus.c.*) are found at the base of the sensory cells and act as supporting cells. Each cell is narrow and long, having a big nucleus at the base. These cells directly rest upon the papilla of the corium and to their bases join small nerve fibres.

There are no rheoreceptors on the barbels.

B. *Gustoreceptors.*

Gustoreceptors or taste buds or end buds are found scattered all over the surface of the body of *Rita rita* and are in abundance over the head and barbels.

Histology.—The taste buds may be compared to close rose buds. Each taste bud is seen resting on a papilla of the corium (Fig. 11, *tas.bd.*, *cor.pap.*), similar to the papilla of the nerve hillock. In a transverse section of the skin of the head, where the epidermis is 480μ thick, taste bud occupies an area of 60μ, and the papilla of the corium occupies the rest of the thickness, i.e. 420μ. Each taste bud is wide at the base and in the middle and measures about 53μ in width. It narrows at its upper end towards the pore, by means of which it communicates to the exterior. The pore is termed gustatory pore (Fig. 12, *gus.op.*) and is 17μ in diameter.

Taste buds on the dorsal lip are longer than those on the body, each measuring 128μ in length on a papilla of the corium 240μ long. Usually each papilla carries a single taste bud, but occasionally two taste buds may be seen resting upon a single papilla (Fig. 13, *tas.bd.*).

On the barbels (Fig. 14), the taste buds lie on short papillae of the corium, because the epidermis is few layered. The corium papilla, in maxillary and mandibular barbels, measures 16μ in length and epidermis is only 64μ in thickness, while the taste bud is about 48μ long. On the nasal barbel (Fig. 15), the taste buds are present on the anterior face, while the posterior flattened surface of the barbel, which faces the narial opening, is completely devoid of taste buds. Each taste bud on the nasal barbel is long and narrow, measuring 80μ in length and 48μ in thickness, resting on a very short raised area of the corium.

Three types of cells are concerned in the formation of a taste bud, namely, (i) the gustatory or neuroepithelial cells, (ii) the sustentacular or supporting cells, and (iii) the basal cells.

(i) *Gustatory or neuroepithelial cells* (Fig. 12, *gus.c.*) are narrow and spindle-shaped with slightly enlarged basal ends. Each cell has a big nucleus in its enlarged end and terminates distally into a delicate protoplasmic hair or cilium (Fig. 12, *cil.*). The cilium, in the skin from the head region, projects out of the gustatory pore, but it does not do so in the trunk region. These cilia have not been described in *Rita rita* by the previous authors (Bhatti, 1938; Islam, 1950*a*).

(ii) *Sustentacular or supporting cells* are of two kinds: the peripheral or tegmental and internal sustentacular cells. The peripheral cells (Fig. 12, *sus.c.*

peri.) are broad with a big centrally placed nucleus and they cover the taste bud at the sides acting as a supporting sheath. Internal sustentacular cells (Fig. 12, *sus.c.int.*) are spindle-shaped and lie scattered among the sensory cells a little below the middle of the cavity of the taste bud.

May (1925), while working on *Amiurus*, observed cells which displayed intermediate stages between typical gustatory cells and sustentacular cells. But no such intermediate stages have been observed in *Rita rita*.

(iii) *Basal cells* (Fig. 12, *bas.c.*) lie at the base of the taste bud. They vary in number from 15 to 25. Their number is not given in *Rita rita* by any of the previous workers. On the nasal barbels their number in a taste bud varies from 18 to 24 (Fig. 15, *bas.c.*), and it is their large number, together with long and narrow gustatory cells, that makes the taste buds on these barbels look much longer than those on the body. The basal cells are not described by Wright (1884) in *Amiurus*. Kappers, Huber and Crosby (1936) describe these cells as broad and connected with the sustentacular cells by means of protoplasmic strands. These strands, however, were not observed in *Rita rita*.

Discussion.

A. *Rheoreceptors.*

1. *Lateral line sense-organs.*—In *Rita rita* (Hamilton), the caudal fin is homocercal like other Teleostei, but the lateral line does not start at the base of the caudal fin in the medial line. It commences as a fine tube at the base of the 4th, 6th and 8th complete fin ray in the dorsal half of the hypochordal lobe of the caudal fin in fishes measuring 31·5 cm., 52 cm. and 41·5 cm. in length respectively. This asymmetrical commencement of lateral line does not agree with that described by Collinge (1894 and 1895) and Smith (1935) in other Teleostean fishes. Collinge (1894) observed that in *Polypodon* and *Acipenser*, where the tail is heterocercal, the lateral line commenced at a distance of about 180 mm. and 13·5 mm. respectively from the tip of the caudal fin. A year later Collinge (1895) described the distribution of the lateral line canal in some Teleostei like *Amiurus*, *Pimeldodus*, *Labeo*, *Salmo* and *Callichthys* and showed the commencement of the lateral line as an exceedingly fine tube from 'base of the caudal fin' or 'at the base of the fin ray'. Smith (1935) classified the fishes according to the position of the lateral line commencement in the caudal region and observed that in Holocephali, Euselachii and Crossopterygii, where the tail is mainly heterocercal, the lateral line coincides with the asymmetry of the tail, while in Actinopterygii, where the tail is homocercal, the lateral line commenced at the base of the caudal fin and figured it as such in *Salmo*. In *Amia*, too, the lateral line is shown starting from the middle of the base of the caudal fin (Collinge, 1895; Smith, 1935).

In *Rita rita* (Hamilton), the asymmetrical commencement of the lateral line canal in the caudal region is remarkably interesting and may be presumed to coincide with the internal asymmetry of the caudal fin and thus afford a strong evidence that a homocercal tail in Teleostei is derived from heterocercy.

The wall of the lateral line canal is described by previous authors as consisting of a single row of undifferentiated epithelial cells as in *Gadus* (Cole, 1898) and in *Mustelus* (Johnson, 1917), or of double row of epithelial cells as in *Amiurus* (Brockelbank, 1925). In *Rita rita*, however, it has been observed that the canal wall in the region of neuromasts consists of two layers of cells, while in the region between the two neuromasts the wall is made up of a single row of well-defined cells.

The sensory receptor cells in each neuromast have big granular nuclei, which are described by previous workers as situated at the base of the sensory cells as in *Gadus* (Cole, 1898) and *Amiurus* (Brockelbank, 1925). In *Rita rita*, however,

these nuclei do not lie at the base but they are in the upper halves of the sensory cells, similar to the condition described by Johnson (1917) in *Mustelus canis*.

Nerve hillocks or scattered pit organs.—The nerve hillocks bear a remarkable resemblance in structure to that of the neuromasts or lateral line organs. This resemblance was also noted previously by Wright (1884), Allis (1889), Walter (1928) and others. Allis (1889), while working on the development of lateral line organs in *Amia*, showed the origin of lateral line as an invagination of the epidermis and observed that 'the sensory canal organs are at first found on the surface of the body, later sink below the surface, but they carry with them the surrounding tissue and by a process of infolding become enclosed in short canals, each containing a single organ. These short canals then become continuous and a single surface opening being left between every two consecutive organs along each line'. The nerve hillocks in *Rita rita* show their origin as a slight invagination of the skin, and their cavity, the neck and the opening are lined by epithelial cells, which are in continuation with the outer surface layer of epidermis. The nerve hillocks do not sink deep into the epidermis, and lie on the papillae of the corium in a superficial position, while in an African Siluroid fish, *Doris*, studied by Bhatti (1938), the nerve hillocks are sunk in pits and lie deep in the epidermis, resting directly on the corium, which does not form any papillae. These different locations of the nerve hillocks in Siluroidea may be regarded as steps, which recapitulate the evolutionary stages in the development of lateral line canal, and in *Rita rita* the superficial position of nerve hillocks, which so closely resemble the neuromasts of the lateral line canal, may be regarded as primitive one.

In nerve hillocks, as in the neuromasts of the lateral line, there are two kinds of cells: sensory and sustentacular. It may also be added that the nerve supply of the nerve hillocks and the neuromasts of the lateral line has the same centre in the brain (Herrick, 1903; Johnston, 1908), and both form part of one and the same acoustico-lateral system.

B. *Gustoreceptors.*

Earliest references to gustoreceptors or taste buds or end buds are those of Leydig (1851), Schulze (1867), Solger (1878), Merkel (1880), Wright (1884) and others. Schulze (1867) assigned the gustatory function to the end buds. Merkel (1880) recognised the structural dissimilarity between the neuromasts and the taste buds, but ascribed to both essentially the same function of 'touch', saying that both the neuromasts of the lateral line system and the terminal buds are tactile organs, the buds being more delicate. He denies the gustatory function to all terminal buds, even those within mouth of all vertebrates below Mammalia (Herrick, 1902). The function assigned to these buds by Herrick (1902) is gustatory or taste and he proved it by experiments. Olmstead (1920), May (1925), Walter (1928), Kappers, Huber and Crosby (1936), Bhatti (1938) and Islam (1950, 1951) also called them taste buds with gustatory function. Bimla Bhatia (1950) described two kinds of sensory buds on the lips of *Glyptothorax telchitta* (Hamilton), and to one of them, she assigns the function of taste but terms them as 'Tangoreceptors'. This term, used by her, literally means the tactile organs or the receptors for touch and pressure. It does not seem appropriate to use this term for the receptors which are purely taste receptors. The second class of sensory buds described by Bimla Bhatia (1950) are termed by her as 'Chemoreceptors', which, according to her account, perform olfactory functions and differ from the so-called 'tangoreceptors' in having spherical shape, while the latter are flask-shaped. In *Rita rita*, the taste buds on the nasal barbels and on the lips are quite long and narrow and differ in shape from those found elsewhere, but nevertheless they are the same receptors, the difference in shape being due to varying thickness of the epidermis in different regions of the body. The distinction of two kinds of receptors into tangoreceptors and chemoreceptors merely on account of their shape

by Bimla Bhatia (1950) is not appreciable and has already been criticised by Islam (1951*a*).

Gustatory receptors are present in abundance on all the barbels and it may safely be presumed that the barbels serve entirely as gustatory receptor organs. The taste buds on the nasal barbels are confined to one side only, while the other side, which faces the narial opening, is completely devoid of taste buds. This is so, because the face of the nasal barbel which is towards the nasal opening presumably does not need gustatory receptors as it lies within the olfactory region.

Summary.

Cutaneous sense-organs in *Rita rita* (Hamilton) include *firstly*, Rheoreceptors comprising lateral line sense-organs and nerve hillocks, and *secondly*, Gustoreceptors or taste buds or end buds.

2. Lateral line starts as a fine tube from the dorsal half of the homocercal caudal fin at the base of 4th, 6th and 8th complete fin ray in *Rita rita* measuring 31·5 cm., 52 cm. and 41·5 cm. in length respectively. This asymmetrical position of the lateral line coincides with the internal asymmetry of the caudal fin and may be said to afford a strong evidence that a homocercal tail in Teleostei is derived from heterocercy.

3. The wall of the lateral line canal is composed of two layers of undifferentiated cells in the region of the neuromast, while in the region between the two neuromasts it is made up of a single row of well-defined cells.

4. The lateral line in its interior contains a large number of sense-organs or neuromasts, their number corresponding to the number of pores on each side. Each neuromast is made of two types of cells: (i) sensory cells which have their nuclei in the dorsal halves and (ii) sustentacular cells having their nuclei in their lower halves. Each neuromast is protected by a thick fibrous investment.

5. Rheoreceptors are entirely absent on all the barbels.

6. The nerve hillocks, or scattered pit organs, show remarkable resemblance in structure to the neuromasts or lateral line sense-organs. The nerve hillocks are lodged on the papillae of corium and show their origin as slight invagination of the skin. They do not sink deep in the epidermis as is the case in an African Siluroid fish, *Doris*, described by Bhatti (1938). These different locations of the nerve hillocks in Siluroidea may be regarded as steps which recapitulate the evolutionary stages in the development of the lateral line sense-organs, and the superficial condition found in *Rita rita* may be regarded as primitive.

7. Gustoreceptors or taste buds or end buds are found scattered all over the body of *Rita rita* (Hamilton), and are found in abundance on the head and barbels. They are purely taste receptors and are composed of three types of cells: the sensory cells, the sustentacular or supporting cells and the basal cells.

8. The taste buds found on the lips and the nasal barbels are long and differ in shape from those found elsewhere. This difference in shape is only due to the varying thickness of the epidermis in different regions of the body. On the body the taste buds rest on a long papilla of the corium, while on the barbels the papilla is very short. On the nasal barbel the taste buds are wanting on the posterior side, which faces the narial opening.

Acknowledgment.

I am extremely grateful to my Professor, Dr. Hamid Khan Bhatti, for suggesting the problem and for his constant encouragement and keen interest in the progress of my work. I am indebted to Professor M. Sharif for affording me facilities to work in the Zoology Laboratories, Government College, Lahore. I, also, owe my thanks to my teacher, Mr. Abu Bakr, for reading my manuscript and encouraging me to complete the investigations.

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STUDIES ON SOUTH INDIAN FUSARIA.

II. Fusaria Isolated from Black Cotton Soils.

By C. V. Subramanian, *I.C.I. Research Fellow, University Botany Laboratory, Madras.*

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Abstract.

An account is given of the Fusaria isolated from black cotton soils collected from Udamalpet (Coimbatore District, South India). The soils were collected from areas known to be severely infested with the cotton wilt *Fusarium* (*Fusarium vasinfectum* Atk.) for years. The Fusaria isolated were:

Section Sporotrichiella
Fusarium poae (Peck) Wr.
F. chlamydosporum Wr. et Rg.
Section Roseum
F. avenaceum (Fr.) Sacc.
Section Gibbosum
F. equiseti (Corda) Sacc.
F. scirpi Lamb. et Fautr.
F. scirpi Lamb. et Fautr. v. *acuminatum* (Ell. et Ev.) Wr.
F. scirpi Lamb. et Fautr. v. *caudatum* Wr.
Section Discolor
F. culmorum (W.G.Sm.) Sacc.
Section Elegans
F. oxysporum Schlecht.
F. vasinfectum Atk.
Section Martiella
F. javanicum Koord.
F. javanicum Koord. v. *radicicola* Wr.
F. solani (Mart.) App. et Wr.
F. solani (Mart.) App. et Wr. v. *Martii* (App. et Wr.) Wr.
F. solani (Mart.) App. et Wr. v. *minus* Wr.
F. solani (Mart.) App. et Wr. v. *striatum* (Sherb.) Wr.

Introduction.

Much emphasis has been placed in recent years on the soil-borne nature of many plant diseases caused by Fusaria. The importance of studying the micro-ecology of fungi in soils has also been emphasised. A prerequisite for such a study is a systematic account of soil fungi. Much of the literature on this subject has been brought together by Gilman (1945). Fusaria from soils have also been investigated by many workers (Hansford, 1926; Reinking and Wollenweber, 1927; Reinking and Manns, 1933, 1934; Reinking, 1934). However, no detailed investigations have been reported on the occurrence of species of *Fusarium* in Indian soils. The only Fusaria recorded as occurring in Indian soils are:

Species.	Locality.	Authority.
(1) *F. oxysporum* Schlecht. ..	Field soil, Lahore; Paddy field soil, Calcutta.	Chaudhuri & Sachar, 1934; Ghatak & Roy, 1939.
(2) *F. dimerum* Penzig ..	Paddy field soil, Calcutta.	Ghatak & Roy, 1939.
(3) *F. solani* (Mart.) App. et Wr. ..	,,	,,
(4) *F. orthoceras* App. et Wr. ..	,,	,,
(5) *F. vasinfectum* Atk. ..	Black cotton soil, Udamalpet, Madras State.	Subramanian, 1946.

The need for a systematic study of soil Fusaria appeared important to the author in the course of his studies on *Fusarium* wilt of cotton plants in South India. During a period of over three years, occurrence of Fusaria in black cotton soils from Udamalpet (Coimbatore District, Madras State) was studied by the author and a large number of Fusaria was isolated from these soils. It was proposed, in a scheme of work submitted to the National Institute of Sciences of India, to make a systematic study of the Fusaria isolated by the author from cotton soils and the results are presented here. Where necessary, the author's isolates have been compared with cultures of *Fusarium* species obtained from the Centraalbureau voor Schimmelcultures, Baarn. The system of Wollenweber and Reinking (1935) has been followed in classifying the isolates.

Methods.

Methods of Isolation.—Two methods were used for the isolation of Fusaria from soils: (*a*) the dilution plate technique (Smith, 1946); and (*b*) the 'root burial' technique (Sadasivan, 1939; Subramanian, 1946), cotton root bits being autoclaved with and without extra nitrogen before being buried in soils. The latter method lacks the precision required for quantitative studies, but was found better than the dilution plate method for isolating Fusaria from soil.

Cultural studies.—The Fusaria isolated were studied in culture following methods recommended by Wollenweber *et al.* (1925). In every case, single spore cultures were made and these were maintained on potato dextrose or oatmeal agar. The *p*H of the media was not adjusted. Throughout the present investigation a minimum of three replicates were studied in each case. Cultures were incubated in diffused light at room temperature (28–31°C.). No advantage was gained by incubating cultures at a lower temperature (19–22°C.).

Cultural characters like amount of aerial mycelium, colour of aerial mycelium, production of sporodochia, etc. were recorded on the 10th, 21st and 30th day after inoculation. Where necessary, examination of cultures was continued beyond the 30th day. Records of colour were made using Maerz and Paul's (1930) Dictionary of Color. References to different colours in this paper are accompanied by Maerz and Paul's numerical designations for these.

General Observations.

Before giving details of the Fusaria isolated, it is necessary to sum up some of the general observations made during this study.

(i) Certain cultural characters like amount of aerial mycelium, its presence or absence, or its colour, could be highly variable for a given isolate. The extent of sporulation could also vary, a given isolate sporulating very well under one set of conditions but not under others.

(ii) Certain other characters like the shape, size and septation of spores, however, did not vary to such a great extent. A given species produced usually the type of spore characteristic for that species, in whatever medium it was grown.

(iii) The majority of the isolates studied were in a state of 'high culture'—the 'hochkultur' of Appel and Wollenweber (1910). Macroconidia were produced in

abundance by these isolates. A few isolates, however, exhibited poor sporulation or none at all. In a few cases no improvement in sporulation could be achieved by the use of different media.

In general, among the isolates studied the following categories may be mentioned:

(*a*) producing chlamydospores, microconidia, and a few macroconidia generally scattered in the aerial mycelium;
(*b*) producing chlamydospores, microconidia and macroconidia—all in abundance;
(*c*) producing a large number of chlamydospores and macroconidia, but fewer or no microconidia; and
(*d*) producing a large number of macroconidia, fewer microconidia, and fewer or no chlamydospores.

(iv) In no case during the course of this investigation was any saltation observed to occur in the isolates studied.

Fusaria Isolated from Soils.

The species are listed under the sections in which they have been placed by Wollenweber and Reinking (1935). Measurements of conidia and chlamydospores are given in microns.

Section Sporotrichiella.

Microconidia 0–1-septate, spherical-ovoid, lemon-, pear-shaped, or fusiform or elliptical. In the species *F. chlamydosporum* and *F. poae* macroconidia are few and are scattered in the aerial mycelium; in *F. sporotrichioides* and *F. tricinctum* they are usually abundant and are produced in sporodochia and pionnotes. Macroconidia resemble those of section *Roseum*. Unlike section *Roseum*, however, chlamydospores are produced in abundance. Colour of stroma carmine to purple red or ochre yellow.

Fusarium poae (Peck) Wr.

Wollenweber apud Lewis, C., Maine agric. Exp. Sta. Bull., 219: 254–58. 1913.—Wollenweber, Ann. mycol., 15: 10. 1917.—Wollenweber & Reinking, Die Fusarien, p. 47, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 32, ic. 1935.—Jamalainen, E. A., Über die Fusarien Finnlands II, Valt. Maatalousk. Julk., 123: 3, ic. 1943.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 109, 127, ic. 1943.

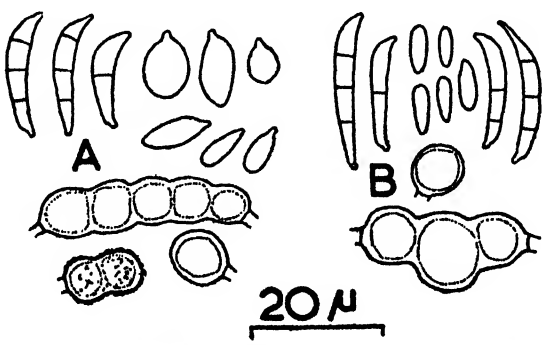

Fig. 1. *A, Fusarium poae*, conidia and chlamydospores from 10 days old culture on oatmeal agar; *B, F. chlamydosporum*, conidia and chlamydospores from 10 days old culture on oatmeal agar.

Wollenweber, Fus. del. 110, 554, 885, 1130.

Conidia numerous, globose or ovoid, sometimes pedicellate, rarely ellipsoidal or piriform, mostly 1-celled, 1-celled conidia measuring 7×5·6 mostly 5–9×4–7 (3–10×3–8), 2-celled 13×7 (6–20×4–10), rarely fusiform. 3-septate conidia rare, but when present measure 25×4. Colour of stroma carmine to purple red, or ochre yellow. Chlamydospores mostly intercalary, in chains or clusters, ochre-brown in colour, diameter 14 (11–17).

Growth on Media.

On potato dextrose agar growth was very fluffy with pinkish tinge or else white, at places yellowish or cream coloured with no development of sporodochia or pionnotes. On oatmeal agar growth was adpressed with no aerial mycelium; substratum was coloured with tinges of cream, Cinnamon Pink (5 C 10) or Roseglow (5 D 9); no sporodochia or pionnotes developed. On Richard's agar growth was white and fluffy, the mycelium being tinged with Ivory (10 B 2) colour in patches; sporodochia and pionnotes none; stroma was well developed and was Oyster white (10 B 1) in colour. On lupin stems growth was fluffy with white mycelium, becoming Ivory (10 B 2) to Peach Blow (10 B 5) with age; sporodochia and pionnotes did not develop. On steamed rice growth was fluffy and the following colours developed in the substratum: Golden rod (10 L 5), Burnt Orange (3 E 12), Laurel pink (3 J 7), Saona (6 F 11).

Measurements of Conidia.

Oatmeal agar, 30 days old:

Conidia globose
0-septate 7·3×5·7 mostly 5·8–8·3×4·9–6·6 (4–10×4–8) .. 94%
1-septate 13×7 (6–20×4–10) 6%
Conidia fusiform-falcate
0-septate 13×4·7 few
1-septate 17×4 few
2-septate 17×4 few
3-septate 25×3·9 few

Potato dextrose agar, 21 days old:

Conidia globose
0-septate 6·9×5·4 mostly 5·8–8·3×4·9–6·6 (3–10×3–8) .. 96%
1-septate 14×6·9 (6–20×4–10) 4%
Conidia fusiform-falcate
0-septate 14×4·5 few
1-septate 16×4·1 few
2-septate 16×3·3 few
3-septate 26×4·1 few

Average of the above measurements:

Conidia globose
0-septate 7×5·6 mostly 5·8–8·3×4·9–6·6 (3–10×3–8)
1-septate 13×7 (6–20×4–10)
Conidia fusiform-falcate
0-septate 13×4·6
1-septate 17×4
2-septate 17×3·6
3-septate 25×4

F. chlamydosporum Wr. et Rg.

Wollenweber & Reinking, Phytopathology, 15 : 156. 1925.—Reinking & Wollenweber, Philip. J. Sci., 32 : 115, ic. 1927.—Wollenweber, Z. Parasitenk., 3 : 475. 1931.—Wollenweber & Reinking, Die Fusarien, p. 47, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 19. 1935.—Doidge, E. M., Bothalia, 3 : 346, ic. 1938.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 107, 128. 1943.

Wollenweber, Fus. del. 883.

Microconidia oval or pyriform, mostly non-septate, 7·8×3 (4–14×1–4), rarely 1-septate 14·3×2·8 (9–22×2–4). Macroconidia rare, when present scattered, falcate, 1–3-septate; 3-septate 26×3 (14–30×1–4); sporodochia none; mycelium floccose; growth on substratum plectenchymatous, of various colours, rose to carmine, sulphuric yellow to dark brown; chlamydospores produced prolifically, globose or pyriform, terminal or intercalary, occurring singly, in pairs, mostly in chains and clusters, 8–16 in diameter. The abundance of large chlamydospores is a characteristic of the species.

Growth on Media.

On potato dextrose agar growth was fluffy in the beginning, the fluffy mycelium collapsing later on; mycelium white, cream (9 D 2) or pinkish (1 B 1) coloured; sporodochia and pionnotes were not produced. On oatmeal agar growth was adpressed with no aerial mycelium, no sporodochia and no pionnotes; there was a weak development of a pink colour due to the stroma. On steamed rice a variety of colours was produced: shades of Glint o'Gold (11 K 4), Golden rod (10 L 5), Burnt Orange (3 E 12) and Laurel pink (3 J 7); these colours deepened to brown with age; aerial mycelium was well-developed, sporodochia and pionnotes were absent. On lupin stems and lupin leaf extract agar growth was white and fluffy with no sporodochia and pionnotes.

Measurements of Conidia.

Oatmeal agar, 21 days old:

0-septate 7·5×3·3 mostly 5–9×2·5–3·9 (4–12×2–4) ..	98%
1-septate 14×3	2%
3-septate 28×3·3	rare.

Potato dextrose agar, 30 days old:

0-septate 8·1×2·6 mostly 6–9×2·5 (4–14×1–4)	41%
1-septate 14·7×2·6 mostly 11–17×2·5 (9–22×2–4) ..	41%
2-septate 18·3×3·3	rare.
3-septate 24×2·8 mostly 19–30×2·5 (14–30×1–4).. ..	18%

Average of the above measurements:

0-septate 7·8×3 mostly 5–9×2·5–3·9 (4–14×1–4)
1-septate 14·3×2·8 mostly 11–17×2·5 (9–22×2–4)
2-septate 18·3×3·3
3-septate 26×3 mostly 19–30×2·5 (14–30×1–4)

Section Roseum.

Macroconidia subulate, thin-walled, slender, falcate to almost straight, cylindrical and of even diameter for a considerable part of their length, tapering

gradually to both ends, apical cell long, sometimes narrow filiform, base more or less pedicellate; orange colour or lighter in mass, brick red or reddish brown when dry; macroconidia borne on the stroma, or in pionnotes and sporodochia, or else, scattered in the aerial mycelium or in false heads. Chlamydospores none; blue sclerotia may or may not be present. Mycelial and stromatic colours developed are: pale white, rose, purple, carmine and yellow.

F. avenaceum (Fr.) Sacc.

Saccardo, Syll. Fung., 4 : 713. 1886.—Lindau in Rabh. Kryptogamenflora, I, 9 : 540. 1909.—Wollenweber, Ann. mycol., 15 : 15. 1917.—Bennett, F. T., Ann. appl. Biol., 15 : 229, ic. 1928.—Wollenweber, Z. Parasitenk., 3 : 460, 476.

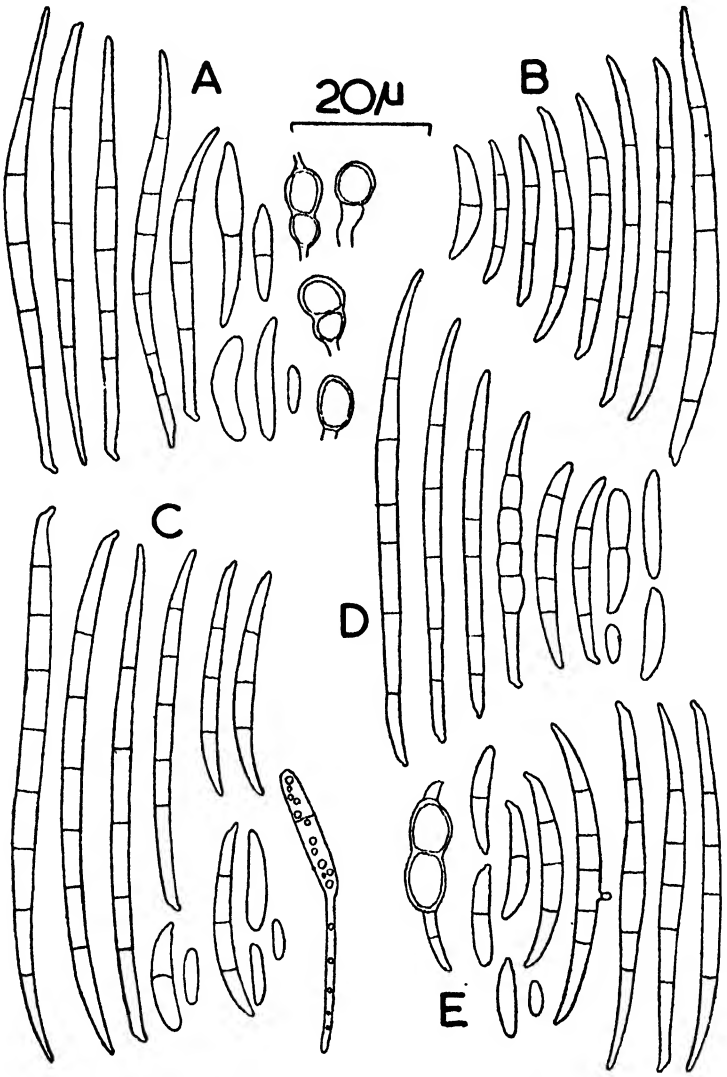

FIG. 2. *Fusarium avenaceum*: conidia and chlamydospores from *A*, 30 days old culture on potato dextrose agar; *B*, 5 days old culture on lupin leaf extract agar; *C*, 6 days old culture on oatmeal agar; *D*, 30 days old culture on oatmeal agar; *E*, 10 days old culture on lupin leaf extract agar with 2% sugar.

1931.—Wollenweber & Reinking, Die Fusarien, p. 53, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 16–18, ic. 1935.—Doidge, E. M., Bothalia, 3 : 348, ic. 1938.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 107, 132, ic. 1943.

Wollenweber, Fus. del. 127, 128, 130–136, 139–161, 163, 164, 178–184, 186–194, 560–568, 572–574, 892, 894–899, 1132, 1133.

Conidia usually in false heads, in sporodochia or pionnotes; in mass orange, becoming darker if drying in a resinous mass, or becoming pink or rose or carmine in a powdery condition; yellow, ochre, and carmine to red brown are the usual stromatic colours; conidia subulate or filiform, long, sometimes more curved near the apex than in the middle, with pedicellate base, mostly 3–5-, rarely 0–2-, 6–7-septate; 3-septate 43×2·9 (21–59×2–5), 5-septate 61×3·3 (36–85×2–5), 7-septate 80×3·2, 0-septate 10×2·6 (4–19×1–4), 1-septate 19×2·9 (11–29×1–4).

Although chlamydospores are stated to be absent in the species (Wollenweber, Zbl. Bakt., Abt. II, 106 : 135. 1943), these have been observed by Bennett (Ann. appl. Biol., 15 : 230. 1928) and also by the writer in isolates of *Fusarium* agreeing with *F. avenaceum* in all other characters.

Growth on Media.

On potato dextrose agar growth was adpressed with no aerial mycelium; conidia were produced prolifically and formed a cream (9 D 2) to salmon (10 A 7) coloured pionnotal layer. On oatmeal agar, growth was adpressed with the substratum coloured light pink, and formation of a pionnotal slime of a cream to salmon colour. On lupin stems there was good development of aerial mycelium with no development of pionnotes. On lupin leaf extract agar growth was white and fluffy with good development of pionnotes. On steamed rice the fungus developed various shades of pink (Hydrangea pink: 2 E 7; Touquet: 4 B 8) with development of cream-coloured pionnotes.

Measurements of Conidia.

Oatmeal agar, 6 days old:

0-septate 11×2·6	mostly 8–14×2·5 (6–19×1–4) ..	.. 5%
1-septate 18×2·9	mostly 14–19×2·4–3·4 (13–27×1–4)	.. 9%
3-septate 45×3	mostly 39–50×2·4–3·4 (31–59×2–5)	.. 10%
4-septate 56×3·2	mostly 51–59×3·3 (48–62×2–5)	.. 23%
5-septate 62×3·3	mostly 56–64×3·3 (53–85×2–5)	.. 43%
6-septate 71×3·5	mostly 66–75×3·3 (54–93×3–5)	.. 10%
7-septate 80×3·2	.. .. ..	.. rare.

Potato dextrose agar, 21 days old:

0-septate 9×2·5	mostly 6–14×2·5 (4–15×1–4) ..	.. 17%
1-septate 21×2·7	mostly 16–24×2·5 (13–29×2–4)	.. 20%
3-septate 43×2·8	mostly 34–52×2·5 (24–57×2–4)	.. 18%
4-septate 58×2·6	mostly 51–60×2·5 (46–69×2–4)	.. 30%
5-septate 66×3	mostly 58–68×2·4–3·4 (53–79×2–4)	.. 15%

Lupin leaf extract agar, 30 days old:

0-septate 10×2·8	mostly 8–12×2·5 (5–15×2–4) ..	.. 16%
1-septate 18×3	mostly 16–22×2·4–3·4 (11–27×2–4)	.. 7%
3-septate 41×3	mostly 33–52×2·4–3·4 (21–59×2–4)	.. 12%
4-septate 49×3·6	mostly 44–54×3·3 (36–60×3–5)	.. 26%
5-septate 56×3·6	mostly 51–64×3–4 (36–75×3–5)	.. 39%

Average of the above measurements:

0-septate 10×2·6 mostly 6–14×2·5 (4–19×1–4)
1-septate 19×2·9 mostly 14–24×2·4–3·4 (11–29×1–4)
3-septate 43×2·9 mostly 33–52×2·4–3·4 (21–59×2–5)
4-septate 54×3·1 mostly 44–60×2·5–3·3 (36–69×2–5)
5-septate 61×3·3 mostly 51–68×2·4–4 (36–85×2–5)
6-septate 71×3·5 mostly 66–75×3·3 (54–93×3–5)
7-septate 80×3·2

On potato dextrose agar the fungus produced chlamydospores. These were intercalary or terminal, 1–2-celled, and sometimes in short chains of usually three or four; 1-celled 7 (4–9); 2-celled 14×7·5 (13–15×6–9).

Section Gibbosum.

Aerial mycelium white or brownish, less frequently yellow, rose to carmine. Stroma ochre-brown to black-brown, sometimes golden yellow to carmine-red. Microconidia scattered more or less freely in mycelium, later disappearing. Macroconidia in sporodochia and pionnotes, pale ochraceous to orange or orange red; sometimes macroconidia are also found in false heads in the mycelium. Conidia dorsiventral, sickle-shaped, with parabolic or hyperbolic curvature, sometimes with acutely arched dorsal line and somewhat less curved ventral line, attenuate at both ends, with filiform or flagella-like apical cell, and very definitely pedicellate base; thin-walled, 3–5–7- or more-septate. Chlamydospores intercalary, seldom terminal, in conidia and in mycelium, globose, single, or in chains or clusters, brown in mass. Spherical, brown or dark blue sclerotia may or may not be present.

F. equiseti (Corda) Sacc.

Saccardo, Syll. Fung., 4 : 707. 1886.—Lindau in Rabh. Kryptogamenflora, I, 9 : 537. 1909.—Wollenweber, Ann. mycol., 15 : 15–16. 1917; Ber. dtsch. bot. Ges., 35 : 734. 1917; Z. Parasitenk., 3 : 330. 1931.—Wollenweber & Reinking, Die Fusarien, p. 63, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 22-23. 1935.—Bennett, F. T., Ann. appl. Biol., 22 : 487, ic. 1935.—Doidge, E. M., Bothalia, 3 : 356, ic. 1938.—Bugnicourt, F., Encyclopedie mycol., 11 : 60, ic. 1939.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 108, ic. 1943.

Wollenweber, Fus. del. 202–208, 210, 211, 596, 597, 919, 920.

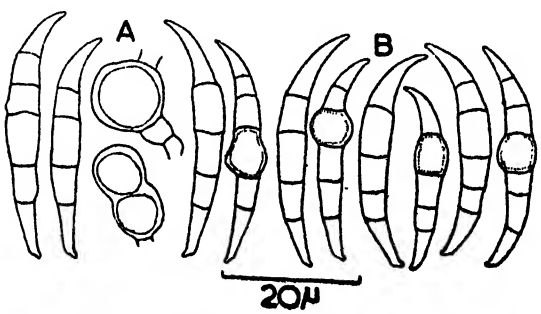

FIG. 3. *Fusarium equiseti*: conidia and chlamydospores from *A*, 2 months old culture on potato dextrose agar; *B*, culture of same age on oatmeal agar.

Conidia few at first, scattered in the white to yellowish, or pink mycelium, 1–2-celled, oval or oblong to fusiform-falcate, disappearing when the typical macroconidia begin to develop. Stroma pale or brown. Macroconidia produced in sporodochia or pionnotes, less frequently scattered in the aerial mycelium; in mass they are at first pale, then ochre to salmon pink. Macroconidia fusiform-falcate, thick in the middle and gradually tapering at either end, with parabolic curvature, straight or bent at the apex, tapering to a fine point, base pedicellate; dorsal side usually more markedly curved than the ventral; septa more or less equidistant, seldom more closely crowded in the middle than at the ends; mostly 5-septate, seldom 3–4-, exceptionally up to 7-septate; 0-septate 10×2·6 (4–17×1–4), 1-septate 14×3 (9–23×2–4), 3-septate 32×3·8 (15–44×2–5), 5-septate 41×4·8 (26–55×3–7), 7-septate 49×4·9. Chlamydospores globose, smooth or rough, intercalary, seldom terminal, 1-celled, in chains or clusters, brown in mass, 13 (8–14) in diameter.

Growth on Media.

On potato dextrose agar growth was fluffy, the aerial mycelium collapsing with age; substratum in young cultures was coloured Vassar rose (3 I 2) to Mayflower (3 J 3) deepening to brown with age; salmon (10 A 7) coloured sporodochia were formed. On oatmeal agar, aerial mycelium formed a compact mat on the agar surface, white to pink (Peach blossom: 1 C 2) coloured; stroma was of a light pink colour, turning dark brown with age; cream coloured sporodochia were produced. On steamed rice a variety of colours developed: Old rose (4 I 2), Rose petal (5 I 4), Ruby (6 G 6); these deepened to dark brown with age. On lupin stems growth was white and fluffy, with abundant development of cream-coloured sporodochia. On lupin leaf extract agar aerial mycelium was white and fluffy; sporodochia did not develop.

Measurements of Conidia.

Oatmeal agar, 6 weeks old:

0-septate 8·5×2·8 mostly 6–10×2·5 (4–12×2–4)	3%
1-septate 14×3·1 mostly 11–17×2·5–3·3 (9–19×2–4) ..	3%
2-septate 18×3·3 mostly 14–23×3·3 (12–25×3–4) ..	2%
3-septate 30×3·7 mostly 23–33×2·5–4·1 (19–37×2–5) ..	15%
5-septate 40×5·7 mostly 36–45×4·9–5·8 (33–52×4–7) ..	77%
6-septate 45×5·5 (43–50×4–6)	rare.
7-septate 45×5·4	rare.

Potato dextrose agar, 7 weeks old:

0-septate 10×2·6 (4–15×1–4)	2%
1-septate 14×2·9 (11–23×2–4)	2%
3-septate 34×3·9 (15–42×2–5)	3%
5-septate 43×4·3 mostly 31–47×3·3–4·9 (29–55×3–5) ..	95%
7-septate 53×4·5	rare.

Lupin stems, 5 weeks old:

0-septate 12×2·4 (5–17×1–4)	1%
1-septate 15×3 (9–19×2–4)	1%
3-septate 33×3·7 mostly 25–41×2·5–4·1 (23–44×2–5) ..	5%
5-septate 41×4·4 mostly 34–47×3·3–4·9 (26–53×3–5) ..	92%

Average of the above measurements:

0-septate 10×2·6 (4–17×1–4)
1-septate 14×3 (9–23×2–4)
2-septate 18×3·3 (12–25×3–4)
3-septate 32×3·8 (15–44×2–5)
5-septate 41×4·8 mostly 31–47×3·3–5·8 (26–55×3–7)
6-septate 45×5·5 (43–50×4–6)
7-septate 49×4·9

F. scirpi Lamb. et Fautr.

Saccardo, Syll. Fung., 11 : 651. 1895.—Wollenweber, Ann. mycol., 15 : 16. 1917; Z. Parasitenk., 3 : 334, ic. 1931.—Wollenweber & Reinking, Die Fusarien, p. 66, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 34-35, ic. 1935.—Doidge, E. M., Bothalia, 3 : 360, ic. 1938.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 109, ic. 1943.

Wollenweber, Fus. del. 198–201, 212–218, 595, 598, 922, 926–929, 1137.

Sporodochia pale, yellowish pink or ochre to salmon in colour; of the size of a pin's head in the beginning, becoming powdery and dry later, or, if moist, coalescing into a slimy pionnotal layer. Spore masses pale to light brown or cinnamon brown. Aerial mycelium loose, cottony, light or brownish, disappearing later. Stroma brown. Conidia resemble those of *F. equiseti*, but the apical cell is more prolonged and pointed, and the curvature of the dorsal side is strongly hyperbolic; septa more closely crowded in the middle of the conidium than at the ends. Microconidia scattered in the mycelium, abundant in young cultures, 0–3-septate, oval, fusiform, kidney- or comma-shaped and also club-shaped to lanceolate. Macroconidia sickle-shaped, mostly 3–5-septate; 0-septate 9×2·8 (5–12×2–4), 1-septate 12×2·9 (6–20×2–4), 3-septate 30×4 (18–42×3–5), 5-septate 40×4·3 (24–50×3–5). Chlamydospores intercalary, seldom terminal, mostly in chains or clusters, brown in colour, seldom single, 11 (7–16) in diameter, globose.

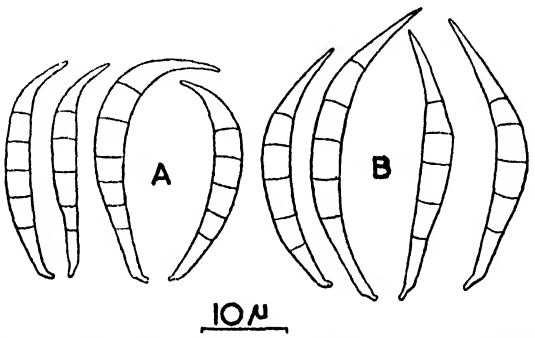

FIG. 4. *Fusarium scirpi*: conidia from *A*, 15 days old culture on potato dextrose agar; 30 days old culture on oatmeal agar.

Growth on Media.

On potato dextrose agar growth was white and cottony, the substratum being coloured Japan rose (3 A 10) to Congo pink (3 C 10); stromatic colour turned brown (Chestnut: 7 E 10) with age. On oatmeal agar growth was adpressed with some aerial mycelium on top of slant; sporodochia and pionnotes of a salmon (10 A 7) colour developed freely; stromatic colour was the same as that on potato dextrose agar. On lupin stems growth was white and fluffy with some development of salmon-coloured sporodochia. On steamed rice the mycelium was white, becoming

Flesh (11 A 2) to Blush (11 A 6); the substratum became brown (Ember: 5 K 10; New Cocoa: 7 A 10; Vandyke brown: 7 A 11) in old cultures.

Measurements of Conidia.

Oatmeal agar, 21 days old:

0-septate	8×2·8 mostly 6–10×2·5–3·3 (5–12×2–4)	.. 7%
1-septate	11×2·9 mostly 8–17×2·5–3·3 (6–20×2–4)	.. 4%
3-septate	29×4 mostly 20–34×3·3–4·9 (18–40×3–5)	.. 31%
4-septate	33×4·1 mostly 26–42×3·3–4·9 (23–45×3–5)	.. 36%
5-septate	40×4·2 mostly 33–45×3·3–4·9 (29–50×3–5)	.. 22%

Potato dextrose agar, 30 days old:

0-septate	9×2·7 mostly 6–10×2·5–3·3 (6–12×2–4)	.. 5%
1-septate	13×2·9 mostly 8–18×2·5–3·3 (6–20×2–4)	.. 3%
3-septate	31×4 mostly 23–37×3·3–4·9 (20–42×3–5)	.. 29%
4-septate	35×4·2 mostly 28–42×3·3–4·9 (23–50×3–5)	.. 29%
5-septate	40×4·4 mostly 34–45×3·3–4·9 (24–50×3–5)	.. 34%

Average of the above measurements:

0-septate	9×2·8 mostly 6–10×2·5–3·3 (5–12×2–4)
1-septate	12×2·9 mostly 8–18×2·5–3·3 (6–20×2–4)
3-septate	30×4 mostly 20–37×3·3–4·9 (18–42×3–5)
4-septate	34×4·2 mostly 26–42×3·3–4·9 (23–50×3–5)
5-septate	40×4·3 mostly 33–45×3·3–4·9 (24–50×3–5)

F. scirpi Lamb. et Fautr. v. *acuminatum* (Ell. et Ev.) Wr.

Wollenweber, Z. Parasitenk., 3 : 335, ic. 1931.—Wollenweber & Reinking, Die Fusarien, p. 67, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 35, ic. 1935.—Doidge, E. M., Bothalia, 3 : 366, ic. 1938.—Wollenweber Zbl. Bakt., Abt. II, 106 : 109, 190, ic. 1943.—Jamalainen, E. A., Über die Fusarien Finnlands III, Valt. Maatalousk. Julk., 124 : 10, ic. 1944.

Wollenweber, Fus. del. 165–168, 170, 569, 930–933.

Stroma plectenchymatous, of various colours, blood red, purple, yellow. Aerial mycelium white or pink. Conidia in sporodochia and pionnotes, salmon in

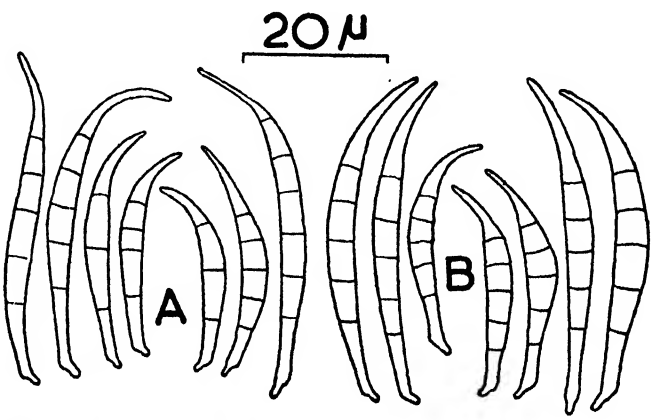

FIG. 5. *Fusarium scirpi* v. *acuminatum*: conidia from *A*, 21 days old culture on oatmeal agar; *B*, on potato dextrose agar.

colour, sickle-shaped, tapering at both ends, apex more or less elongated, base pedicellate or papillate, occasionally rounded to truncate, mostly 5-septate, less often 3-4-septate, exceptionally 0–2-septate; 0-septate 9×2·8 (6–14×2–4), 1-septate 12×2·9 (8–17×2–4), 3-septate 32×3·6 (20–47×2–5), 5-septate 48×3·9 (27–62×3–5). Chlamydospores intercalary, seldom terminal, mostly in chains and clusters, globose, 1-celled 11 (8–17), 2-celled 17×10 (13–20×7–13), in mass brown.

Growth on Media.

On potato dextrose agar growth was fluffy with aerial mycelium of a white or Golden wheat (11 D 7) to yellow ochre (11 L 7) or Blossom (2 F 7) to Coral pink (2 F 9) colour, deepening to Weigelia (3 I 3) or Persian pink (3 H 4). On oatmeal agar growth was adpressed with some aerial mycelium on the top of the slant; colour of the substratum was Weigelia (3 I 3) or Persian pink (3 H 4); sporodochia of a salmon colour developed. On lupin stems growth was white and fluffy with development of sporodochia. On steamed rice aerial mycelium was white; substratum was coloured with Pineapple (11 J 2), Colonial Y (11 K 3), Rose Marie (2 I 2), Camellia (2 J 4).

Measurements of Conidia.

Oatmeal agar, 5 weeks old:

3-septate 33×3·7 mostly 29–35×3·3–4·2 (26–40×3–5)	..	18%
4-septate 35×3·8 mostly 30–39×3·3–4·2 (25–44×3–5)	..	22%
5-septate 48×3·9 mostly 36–53×3·3–4·2 (33–62×3–5)	..	60%

Potato dextrose agar, 3 weeks old:

0-septate 9×2·8 mostly 8–10×2·5–3·3 (6–14×2–4)	..	3%
1-septate 12×2·9 mostly 10–14×2·5–3·3 (8–17×2–4)	..	1%
3-septate 30×3·4 mostly 23–34×3·3 (20–47×2–5)	..	10%
4-septate 36×3·6 mostly 29–42×3·3–4·2 (23–50×3–5)	..	15%
5-septate 48×3·8 mostly 39–54×3·3–4·2 (27–62×3–5)	..	71%

Average of the above measurements:

0-septate 9×2·8 mostly 8–10×2·5–3·3 (6–14×2–4)
1-septate 12×2·9 mostly 10–14×2·5–3·3 (8–17×2–4)
3-septate 32×3·6 mostly 23–35×3·3–4·2 (20–47×2–5)
4-septate 36×3·7 mostly 29–42×3·3–4·2 (23–50×3–5)
5-septate 48×3·9 mostly 36–54×3·3–4·2 (27–62×3–5)

F. scirpi Lamb. et Fautr. v. *caudatum* Wr.

Wollenweber, Z. Parasitenk., 3 : 336. 1931.—Wollenweber & Reinking, Die Fusarien, p. 68, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 35. 1935.—Bugnicourt, F., Encyclopedie mycol., 11 : 70, ic. 1939.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 109. 1943.

Wollenweber, Fus. del. 599, 600, 934, 935.

Conidia comparatively slender, typically with a tail or somewhat whiplike apical cell, base pedicellate with well-marked heel, formed in sporodochia and pionnotes of an ochre to salmon colour, mostly 5-septate; 3-septate 29×3·7 (19–39 ×2–5), 4-septate 35×3·6 (26–45×3–5), 5-septate 41×3·7 (28–54×3–5). Chlamydospores produced in large numbers, mostly intercalary, 11 (7–17) in diameter. Stroma brown.

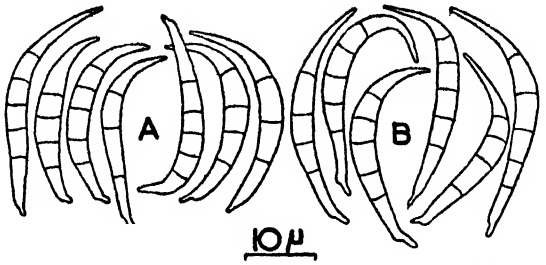

FIG. 6. *Fusarium scirpi* v. *caudatum*: conidia from *A*, 30 days old culture on potato dextrose agar; *B*, on oatmeal agar.

Growth on Media.

On potato dextrose agar growth was slightly fluffy with white cottony aerial mycelium in patches and good development of sporodochia and pionnotes of a light pink colour. On oatmeal agar there was no aerial mycelium and growth was adpressed with profuse development of sporodochia coalescing to form a slimy pionnotes of a honey dew (9 B 8) to rufous (10 A 10) colour. On lupin stems there was better development of aerial mycelium and sporodochia of a salmon (10 A 7) colour. On steamed rice aerial mycelium was scanty to none with development of spore masses of a honey dew to rufous or salmon colour.

Measurements of Conidia.

Oatmeal agar, 4 weeks old:

3-septate 28×3·4 mostly 24–32×3·3 (19–34×2–5)	..	13%
4-septate 33×3·4 mostly 29–35×3·3 (26–40×3–5)	..	24%
5-septate 34×3·5 mostly 31–37×3·3–4·2 (28–44×3–5)	..	63%

Potato dextrose agar, 6 weeks old:

3-septate 30×3·9 mostly 25–35×3·3–4·2 (23–39×2–5)	..	17%
4-septate 36×3·8 mostly 29–40×3·3–4·2 (26–45×3–5)	..	20%
5-septate 47×3·8 mostly 40–52×3·3–4·2 (36–54×3–5)	..	63%

Average of the above measurements:

3-septate 29×3·7 mostly 24–35×3·3–4·2 (19–39×2–5)
4-septate 35×3·6 mostly 29–40×3·3–4·2 (26–45×3–5)
5-septate 41×3·7 mostly 31–52×3·3–4·2 (28–54×3–5)

Section Discolor.

Macroconidia comparatively thick-walled, fusiform to sickle-shaped, tapering at both ends, curved (dorsal side convex, ventral side less curved, usually concave but sometimes somewhat convex); apex constricted like the neck of a bottle, curved and rostrate, or conical to truncate or rounded; base pedicellate when fully developed and mature. Sporodochia and pionnotes ochre, salmon pink or orange. Some species have small or medium-sized conidia, which are pedicellate, 0–3- or more-septate, oval, fusiform to cylindrical, straight or curved; these may predominate or may disappear when sporodochia are formed. Other species have some comparatively slender conidia. The stroma is flat, effuse, plectenchymatous, sclerotially erumpent in places, and coloured variously: pale, carmine to purple red, yellow, brown or rarely blue; in a few it is pale and homogeneous. Spherical sclerotia may or may not be present; when present they are blue, brown or

colourless. Aerial mycelium well-developed, white, pink, or tinged with the colour of the stroma. Chlamydospores few, terminal or intercalary, single, in chains or clusters, brown in mass.

F. culmorum (W.G. Sm.) Sacc.

Saccardo, Syll. Fung., 11 : 651. 1895.—Wollenweber, J. agric. Res., 2 : 260, ic. 1914; Ann. mycol., 15 : 21. 1917.—Sherbakoff, C. D., Cornell Univ. agric. Exp. Sta. Mem., 6 : 240. 1915.—Bennett, F. T., Ann. appl. Biol., 15 : 225, ic. 1928.—Wollenweber, Z. Parasitenk., 3 : 360, ic. 1931.—Wollenweber & Reinking, Die Fusarien, p. 79, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 21. 1935.—Doidge, E. M., Bothalia, 3 : 380, ic. 1938.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 108, ic. 1943.

Wollenweber, Fus. del. 330–337, 613, 943–945, 1147–1149.

Conidia at first scattered in the aerial mycelium, or in false heads, sometimes forming a pionnotal layer later, or formed in sporodochia; in mass coloured variously, yellow, pink, then ochre to coffee brown, often becoming more or less tinged with the purple red and golden yellow to ochre brown colour of the stroma. Conidia spindle- to sickle-shaped, gradually or abruptly attenuate at both ends; apical cell sometimes rostrate, constricted like the neck of a bottle; base pedicellate, wall thick with distinct septa. Conidia 5-septate, less frequently 3-4- or 6-septate; 3-septate 31×5·6 (20–42×4–7), 4-septate 34×5·8 (23–43×4–7), 5-septate 38×6·2 (26–53×4–7), 6-septate 40×6. Chlamydospores mostly intercalary, globose or oval, in conidia and in mycelium, single, 2-celled, or in chains and clusters, brown in mass, 1-celled 11 (9–14), 2-celled 16–22×8–17.

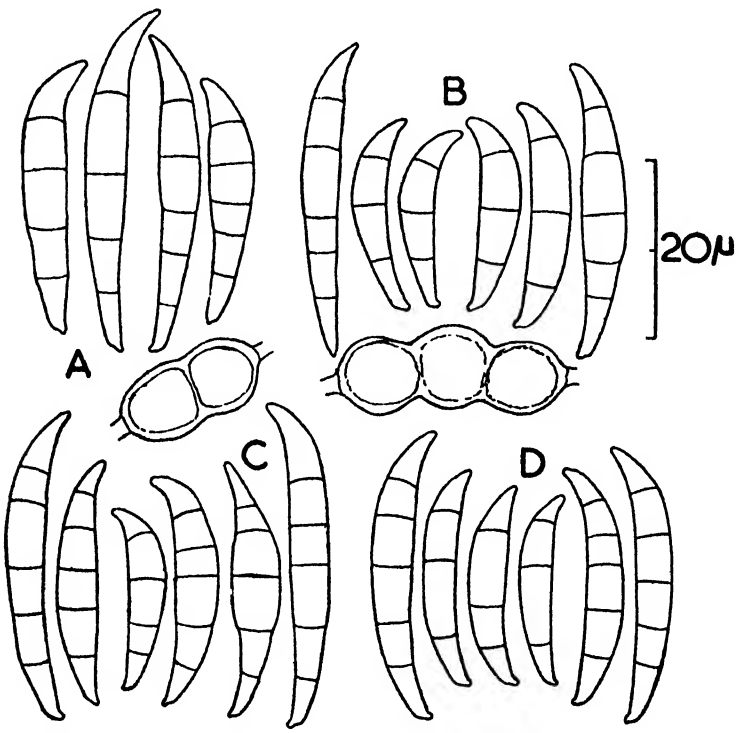

FIG. 7. *Fusarium culmorum*: conidia and chlamydospores from *A*, 30 days old culture on potato dextrose agar; *B*, from 65 days old culture; *C*, from 35 days old culture on oatmeal agar; *D*, from 70 days old culture.

Growth on Media.

On potato dextrose agar growth was white and fluffy with the substratum coloured Rose Nilsson (2 J 3), Camellia (2 J 4) to Jack rose (3 J 6) and Cherry blossom (4 J 4); sporodochia were of a cream (9 D 2) to salmon (10 A 7) colour. On oatmeal agar aerial mycelium was well developed, white or of a light pink (Corinthian pink: 3 G 1) colour in patches; stroma was coloured Eugenia R (3 K 2) to Zinnia (4 L 2); sporodochia were of a light yellow (Martius Y : 9 I 1; Pinard Y : 9 J 2; Jasmine : 9 K 4) colour. On steamed rice growth was very fluffy and the striking colours developed were various shades of carmine, pink and red (Persian pink: 3 H 4; Eugenia R: 3 K 2; Mayflower; 3 J 3; Spinel R: 3 H 5; Dianthus: 5 K 3) later turning brown (Garnet Brown: 6 L 9). On lupin stems growth was fluffy, aerial mycelium was white to slightly cream or yellow coloured; sporodochia were present.

Measurements of Conidia.

Oatmeal agar, 6 weeks old:

3-septate 30×5·5 mostly 25–35×4·9–6·6 (21–37×4–7) .. 11%
4-septate 33×5·8 mostly 25–37×4·9–6·6 (24–40×4–7) .. 10%
5-septate 37×6·2 mostly 31–40×5·1–6·6 (26–51×4–7) .. 79%

Potato dextrose agar, 7 weeks old:

3-septate 32×5·7 mostly 25–40×4·9–6·6 (20–42×4–7) .. 9%
4-septate 35×5·9 mostly 27–40×4·9–6·6 (23–43×4–7) .. 8%
5-septate 38×6·1 mostly 32–42×4·9–6·6 (29–53×4–7) .. 83%

Average of the above measurements:

3-septate 31×5·6 mostly 25–40×4·9–6·6 (20–42×4–7)
4-septate 34×5·8 mostly 25–40×4·9–6·6 (23–43×4–7)
5-septate 38×6·2 mostly 31–42×4·9–6·6 (26–53×4–7)

Section Elegans.

Microconidia and macroconidia present. Microconidia oval, ellipsoidal kidney-shaped or straight, 5–12×2·2–3·5, single on free conidiophores, or in false heads, produced in abundance. Macroconidia in sporodochia or in pionnotes. Conidial masses formed on an erumpent or flat, plectenchymatous or sclerotial stroma. In some species the macroconidia are elongated, fusiform to subulate, tapering at both ends or slightly constricted; in others they are more compact, fusiform-falcate, usually constricted and abruptly curved at the apex, and pedicellate or papillate at the base. Macroconidia dorsiventral to almost cylindrical, thin-walled, usually with 3, sometimes up to 5, delicate septa, 3-septate 27–46×3–5, 5-septate 50–60×3–5; in mass pale, isabellinous, brownish-white, flesh colour to salmon orange. Mycelium white or tinged with the colour of the stroma. Stroma pale or pink, orange or purple red, plectenchymatous, effuse or raised, more or less erumpent or sclerotial. Chlamydospores abundant, terminal and intercalary, in mycelium and conidia. Sclerotia sometimes present, rough, brown, blue or pale.

F. oxysporum Schlechtendahl

Saccardo, Syll. Fung., 4 : 705. 1886.—Lindau in Rabh. Kryptogamenflora, I, 9 : 525. 1909.—Wollenweber, Phytopathology, 3 : 28, ic. 1913; J. agric. Res., 2 : 268. 1914.—Sherbakoff, C. D., Cornell Univ. agric. Exp. Sta. Mem., 6 : 220,

ic. 1915.—Wollenweber, Ann. mycol., 15 : 24. 1917.—Reinking & Wollenweber, Philip. J. Sci., 32 : 187, ic. 1927.—Wollenweber, Z. Parasitenk., 3 : 416, ic. 1931. Wollenweber & Reinking, Die Fusarien, p. 117, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 31, ic. 1935.—Doidge, E. M., Bothalia, 3 : 421, ic. 1938.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 109, ic. 1943.

Wollenweber, Fus. del. 378, 1005–1007, 1170–1174.

Stroma brownish white to violet, plectenchymatous, smooth, effuse. Under humid conditions aerial mycelium may be present over the stroma, sporodochia or pionnotes being produced later. Microconidia 1-2-celled, oval to kidney-shaped, abundant, scattered in the aerial mycelium or in false heads. Macroconidia 3-(4-5)-septate, spindle- to sickle-shaped, curved or almost straight, definitely or weakly pedicellate. Conidia 0-septate 8×2·7 (4–14×2–4), 1-septate 14×3 (8–24×2–4), 3-septate 33×3·9 (21–50×2–5), 5-septate 42×4·3 (37–50×4–5). Chlamydospores terminal and intercalary, globose, smooth or rugulose, 1-celled 7·4 (5–10), 2-celled 10×7 (8–14×5–9).

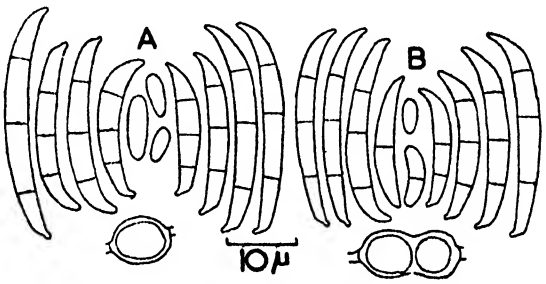

FIG. 8. *Fusarium oxysporum*: conidia and chlamydospores from *A*, 15 days old culture on potato dextrose agar; *B*, 21 days old culture on oatmeal agar.

Growth on Media.

On potato dextrose agar growth was velvetty, white to lilac (3 G 7) or wild rose (3 I 7) and tinges of Vanda (43 E 4) or Crocus (43 F 4); substratum was coloured Corinth (46 J 2) to Indian purple (47 J 2) or Perilla purple (47 J 3). On oatmeal agar aerial mycelium was poorly developed; the substratum was coloured Crushed violets (45 G 5) or Old lilac (45 H 6); spores were produced in a pionnotes of a Monkey skin (5 B 9) colour. On lupin stems growth was fluffy with white, cottony aerial mycelium and development of sporodochia of a Misty morn (5 C 7) colour. On steamed rice a variety of colours developed: Rose Marie (2 I 2), Begonia rose (2 K 2), Vassar rose (3 I 2), Bridal rose (3 F 3) and Azalea (4 J 3).

Measurements of Conidia.

Oatmeal agar, 27 days old:

0-septate 9×3	mostly 7–10×2·5–3·3 (6–14×2–4)	.. 37%
1-septate 16×3·1	mostly 13–19×2·5–3·3 (11–24×2–4)	.. 35%
2-septate 21×3	mostly 19–24×2·5–3·3 (18–25×2–4)	.. 6%
3-septate 29×3·6	mostly 26–32×3·3–4·2 (21–37×2–5)	.. 22%

Potato dextrose agar, 35 days old:

0-septate 7×2·4	mostly 5–9×2·5 (4–13×2–4)	.. 38%
1-septate 13×3·1	mostly 11–17×2·5–3·3 (8–20×2–4)	.. 31%
2-septate 23×3·2	mostly 14–30×2·5–3·3 (11–33×2–4)	.. 4%
3-septate 35×4·2	mostly 27–42×3·3–4·9 (23–50×3–5)	.. 27%

Lupin stems, 21 days old:

0-septate	7×2·6 mostly 6–10×2·5 (5–12×2–3)	.. 22%
1-septate	14×2·9 mostly 10–18×2·5–3·3 (8–20×2–4)	.. 14%
2-septate	20×3 mostly 15–27×2·5–3·3 (13–30×2–4)	.. 4%
3-septate	34×4 mostly 27–37×4·2 (23–40×3–5)	.. 23%
4-septate	38×4·2 mostly 35–43×4·2 (33–47×4-5)	.. 18%
5-septate	42×4·3 mostly 39–45×4·2 (37–50×4-5)	.. 19%

Average of the above measurements:

0-septate	8×2·7 mostly 5–10×2·5–3·3 (4–14×2–4)
1-septate	14×3 mostly 10–19×2·5–3·3 (8–24×2–4)
2-septate	21×3·1 mostly 14–30×2·5–3·3 (11–33×2–4)
3-septate	33×3·9 mostly 26–42×3·3–4·9 (21–50×2–5)
4-septate	38×4·2 mostly 35–43×4·2 (33–47×4–5)
5-septate	42×4·3 mostly 39–45×4·2 (37–50×4–5)

F. vasinfectum Atk.

Atkinson, G. F., Alabama agric. Exp. Sta. Bull., 41 : 19, ic. 1892.—Lindau in Rabh. Kryptogamenflora, I, 9 : 563. 1909.—Saccardo, Syll. Fung., 22 : 1481. 1913.—Wollenweber, Phytopathology, 3 : 29. 1913; Ann. mycol., 15 : 24. 1917; Z. Parasitenk., 3 : 423–425, ic. 1931.—Wollenweber & Reinking, Die Fusarien, p. 124–126, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 39-40, 1935.—Doidge, E. M., Bothalia, 3 : 432, ic. 1938.—Bugnicourt, F., Encyclopedie mycol. 11 : 114, ic. 1939.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 110, ic. 1943.—Subramanian, C. V., Proc. Nat. Inst. Sci. India, 18 : 273-85. 1952.

Wollenweber, Fus. del. 376.

Synonyms: Subramanian (1952) has shown that the following should be considered synonyms of *F. vasinfectum* Atk.:

F. vasinfectum Atk. f.1 Wr., Z. Parasitenk., 3 : 423. 1931. Wollenweber, Fus. del. 377, 1018, 1190.

F. vasinfectum Atk. f.2 Wr. et Rg., Die Fusarien, p. 125. 1935. Wollenweber, Fus. del. 1191.

F. vasinfectum Atk., v. *lutulatum* (Sherb.) Wr., Z. Parasitenk., 3 : 424. 1931. Wollenweber, Fus. del. 380, 1019, 1192.

F. vasinfectum Atk. v. *zonatum* (Sherb.) Wr., Z. Parasitenk., 3 : 424. 1931. Wollenweber, Fus. del. 392, 1020.

F. vasinfectum Atk. v. *zonatum* (Sherb.) f.2 (Lk. et Bail.) Wr., Z. Parasitenk., 3 : 425. 1931. Wollenweber, Fus. del. 1021 in nota.

Cultural characters and morphology of the author's isolates have been given in detail elsewhere (Subramanian, 1952).

Section Martiella.

Microconidia and macroconidia present. Microconidia mostly 1-celled, small, oval to oblong. Macroconidia dorsiventral, spindle- to sickle-shaped, thick-walled, pluriseptate, septa distinct; curvature more decided near the apex and slight in the central part of the conidium, apex rounded or tapering; base pedicellate or mamillate. The median diameter of the conidia is of diagnostic value in this section. Conidial masses pale, white, yellowish or brownish, or in older cultures darker, honey colour to amber, or becoming tinged with the colour of the stroma. Stroma yellow brown to dark blue. Sclerotial bodies, when present, brown, green,

violet or blue-black. Chlamydospores abundant, terminal and intercalary, 1-2-celled, in chains or clusters, smooth or rough.

F. javanicum Koord.

Koorders, Verh. Koninkl. Akad. Wetensch. Amsterdam, II, 13 : 247, ic. 1907.—Saccardo, Syll. Fung., 22 : 1482. 1913.—Wollenweber, Ann. mycol., 15 : 26. 1917.—Reinking & Wollenweber, Philip. J. Sci., 32 : 232, ic. 1927.—Wollenweber, Z. Parasitenk., 3 : 452, 483. 1931.—Wollenweber & Reinking, Die Fusarien, p. 131, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 25, ic. 1935.—Doidge, E. M., Bothalia, 3 : 443, ic. 1938.—Bugnicourt, F., Encyclopedie mycol., 11 : 125, ic. 1939.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 108, 178, ic. 1943.

Wollenweber, Fus. del. 349, 424, 426–428, 1025–1027.

Conidia brownish white to light brown in mass, becoming coffee brown or tinged with the colour of the stroma with age. Stroma leathery to gelatinous, usually olive green to olive brown. Microconidia 1-2-celled, usually scattered in the aerial mycelium. Macroconidia in sporodochia and pionnotes, falcate, slightly curved, often more decidedly so at the apex, constricted at both ends, more or less pedicellate at the base, 3–5-septate. Conidia 0-septate 13×3·7 (6–20×2–5), 1-septate 21×4·3 (14–39×3–6), 3-septate 37×4·7 (23–49×4–5), 5-septate 48×4·9 (36–58×4-5). Chlamydospores 1-2-celled, 1-celled 9 (6–12), 2-celled 13×9·6 (9–17×8–12).

Growth on Media.

On potato dextrose agar the aerial mycelium was pale white, but sparse; there was good development of sporodochia of a pale dull white colour or often Smoke-grey (28 A 2) in colour; colour of stroma was Vanilla (10 C 3) to India buff (12 E 5). On oatmeal agar growth was adpressed with slight development of white aerial mycelium at the bottom and the top of the slant, and with profuse development of sporodochia of a New silver (11 B 1) colour, tending to become blue; stroma was of an Italian straw (11 D 2) colour. On Richard's agar growth was fluffy and white, with no sporodochia or pionnotes. On lupin stems growth was slightly fluffy and white, with good development of sporodochia of a cream (9 D 2) to maple (11 E 4) colour, tending to become gnaphalium green (28 A 4) with age. On steamed rice the mycelium was white in the beginning becoming later buff coloured; sporodochia were present.

Measurements of Conidia.

Oatmeal agar, 15 days old:

0-septate 12×3·3 mostly 9–14×3·3 (6–20×2–5) ..	.. 2%
1-septate 23×4·1 mostly 19–25×4·2 (14–29×3–5)	.. 5%
2-septate 27×4·3 mostly 24–30×4·2 (23–34×4-5)	.. 11%
3-septate 33×4·7 mostly 29–35×4·2–4·9 (26–40×4-5)	.. 82%

Potato dextrose agar, 21 days old:

0-septate 13×4 mostly 11–14×4·2 (9–15×2–5) ..	.. 2%
1-septate 19×4·4 mostly 16–22×4·1–4·9 (14–24×3–6)	.. 7%
2-septate 23×4·2 mostly 19–27×4·2 (18–30×4-5)	.. 5%
3-septate 37×4·7 mostly 34–42×4·2–4·9 (23–42×4-5)	.. 67%
4-septate 40×4·9 mostly 36–42×4·9 (33–47×4-5)	.. 18%
5-septate 48×4·9 mostly 38–54×4·9 (36–58×4-5)	.. 1%

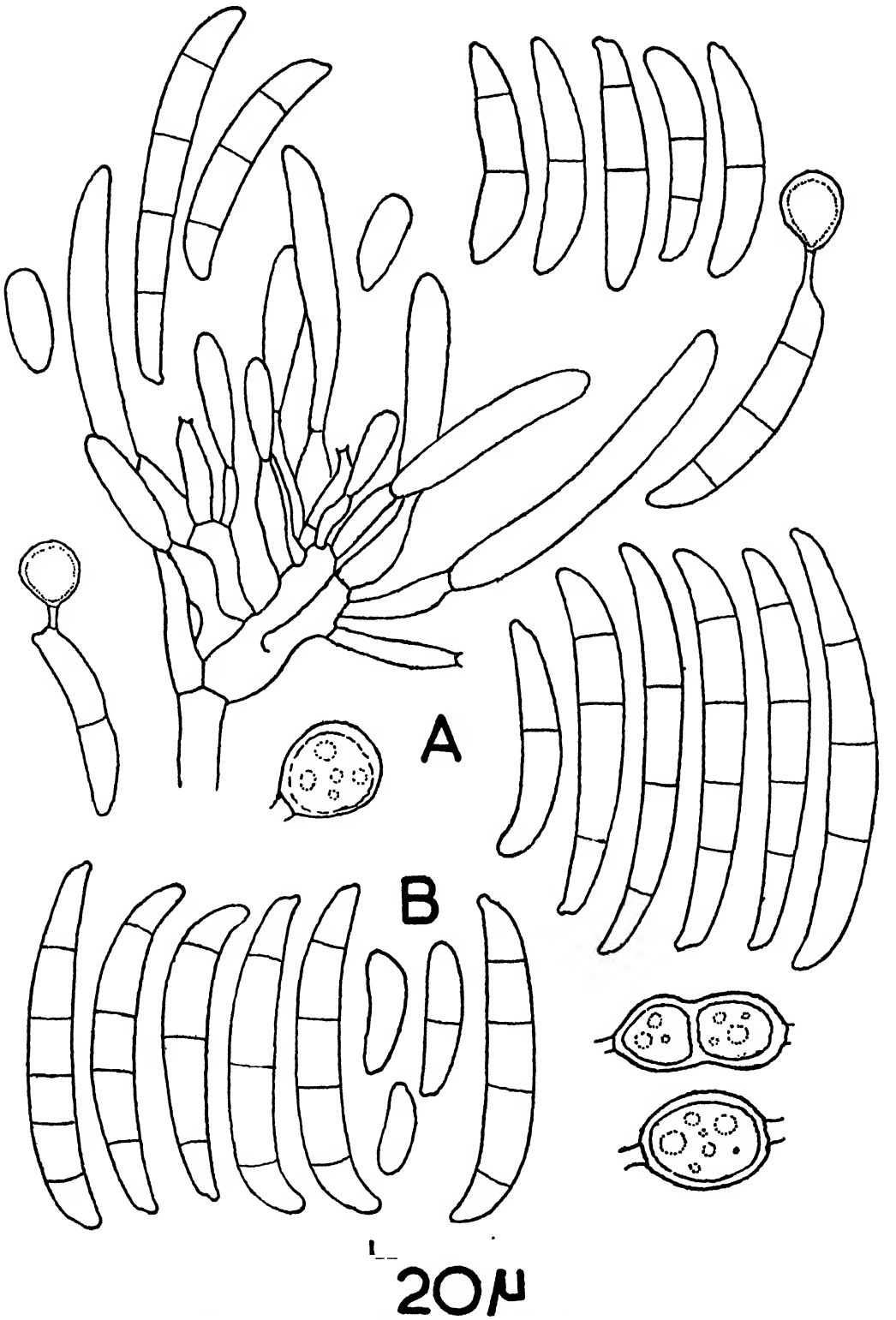

FIG. 9. *Fusarium javanicum*: conidia and chlamydospores from *A*, 10 days old culture on oatmeal agar; *B*, from culture of same age on potato dextrose agar.

Lupin stems, 10 days old:

0-septate	14×3·9 mostly 11–15×3·3–4·2 (8–17×3–5)	.. rare.
1-septate	22×4·4 mostly 18–25×4·2–4·9 (14–39×3–5)	.. 1%
2-septate	38×4·5 mostly 34–40×4·2–4·9 (28–42×3–5)	.. 17%
3-septate	42×4·7 mostly 38–44×4·2–4·9 (33–49×4-5)	.. 55%
4-septate	46×4·8 mostly 44–50×4·2–4·9 (41–54×4-5)	.. 27%

Average of the above measurements:

0-septate	13×3·7 mostly 9–15×3·3–4·2 (6–20×2–5)
1-septate	21×4·3 mostly 16–25×4·1–4·9 (14–39×3–6)
2-septate	29×4·3 mostly 19–40×4·2–4·9 (18–42×3–5)
3-septate	37×4·7 mostly 29–44×4·2–4·9 (23–49×4-5)
4-septate	43×4·9 mostly 36–50×4·9 (33–54×4-5)
5-septate	48×4·9 mostly 38–54×4·9 (36–58×4-5)

F. javanicum Koord. v. *radicicola* Wr.

Wollenweber, Z. Parasitenk., 3 : 286, 452, 464, 483, ic. 1931.—Wollenweber & Reinking, Die Fusarien, p. 129, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 25. 1935.—Doidge, E. M., Bothalia, 3 : 446, ic. 1938.—Bugnicourt, F., Encyclopedie mycol., 11 : 121, ic. 1939.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 108, 179, ic. 1943.

Wollenweber, Fus. del. 423, 632, 1023, 1024.

Microconidia abundant, 1-celled or septate, scattered in the mycelium or formed in false heads. Macroconidia in sporodochia, less often in pionnotes, brownish white in mass, becoming darker with age, or tinged with the colour of the stroma. Strema coloured olive brown to coffee brown. Macroconidia fusiform to subfalcate, curved, more definitely curved or constricted at the apex, subpedicellate at the base, 3-septate, rarely 4-septate; 0-septate 10×3·3 (5–19×2–5), 1-septate 18×3·8 (13–25×3–5), 3-septate 35×4·5 (18–54×3–6), 4-septate 47×4·6 (41–55×4-5). Chlamydospores terminal and intercalary, 1-2-celled, in chains or

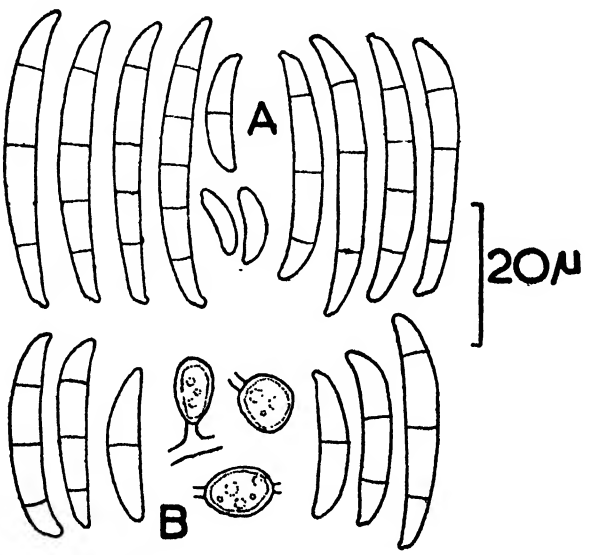

FIG. 10. *Fusarium javanicum* v. *radicicola*: conidia and chlamydospores from *A*, 21 days old culture on oatmeal agar; *B*, culture of same age on potato dextrose agar.

clusters, smooth or verrucose, 1-celled (globose) 8·2 (6–10), (pyriform) 8·3×8·1 (7–10×7–10), 2-celled 12×8 (10–14×6–10).

Growth on Media.

On potato dextrose agar growth was adpressed with only slight development of aerial mycelium at the top of the slant, and development of a cream (9 D 2) coloured pionnotes later turning Ageratum blue (43 C 3). On oatmeal agar also the growth was adpressed with no aerial mycelium but good development of pionnotes of a Flesh (11 B 2) colour; stroma was of a White jade (10 A 2) to Flesh (11 B 2), or Ageratum blue (43 C 3) colour. On lupin stems aerial mycelium was absent, but cream (9 D 2) coloured pionnctes developed. On steamed rice the aerial mycelium was white and felt-like, with late development of sporodochia of a Rattan (11 K 6) to Serpentine Gr (14 K 3) colour.

Measurements of Conidia.

Oatmeal agar, 30 days old:

0-septate	10×3·1 mostly 8–12×2·5–3·3 (6–14×2–5)	.. 18%
1-septate	18×3·9 mostly 16–20×3·3–4·2 (14–24×3–5)	.. 13%
3-septate	42×4·6 mostly 36–47×4·2–4·9 (24–54×4·5)	.. 63%
4-septate	47×4·6 mostly 44–50×4·2–4·9 (41–55×4·5)	.. 6%

Potato dextrose agar, 10 days old:

0-septate	13×3 7 mostly 9–15×3·3–4·2 (8–19×2–5)	.. 52%
1-septate	19×4·3 mostly 16–22×4·2 (13–25×4·5)	.. 20%
2-septate	28×4·8 mostly 26–30×4·2–4·9 (24–32×4–6)	.. 5%
3-septate	32×5·1 mostly 29–34×4·9 (28–39×4–6)	.. 23%

Lupin stems, 35 days old:

0-septate	8×3 mostly 6–10×3·3–4·2 (5–15×2–5)	.. 10%
1-septate	18×3·2 mostly 16–22×3·3 (13–24×3·4)	.. 20%
2-septate	23×3·9 mostly 20–27×3·3–4·2 (17–30×3–5)	.. 3%
3-septate	30×3·8 mostly 21–34×3·3–4·2 (18–42×3–5)	.. 67%

Average of the above measurements:

0-septate	10×3·3 mostly 6–15×2·5–4·2 (5–19×2–5)
1-septate	18×3·8 mostly 16–22×3·3–4·2 (13–25×3–5)
2-septate	26×4·4 mostly 20–30×3·3–4·9 (17–32×3–6)
3-septate	35×4·5 mostly 21–47×3·3–4·9 (18–54×3–6)
4-septate	47×4·6 mostly 44–50×4·2–4·9 (41–55×4·5)

F. solani (Mart.) App. et Wr.

Appel & Wollenweber, Arb. K. Biol. Anst. Land.—u. Forstw., 8 : 65, ic. 1910. Wollenweber, Phytopathology, 3 : 30, 49, ic. 1913.—Sherbakoff, C. D., Cornell Univ. agric. Exp. Sta. Mem., 6 : 251, ic. 1915.—Wollenweber, Ann. mycol., 15 : 25, 26. 1917.—Reinking & Wollenweber, Philip. J. Sci., 32 : 210, ic. 1927.—Wollenweber, Z. Parasitenk., 3: 450–452, 483, ic. 1931.—Wollenweber & Reinking, Die Fusarien, p. 135, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 36, 37, ic. 1935.—Doidge, E. M., Bothalia, 3 : 447, ic. 1938.—Bugnicourt, F., Encyclopedie mycol., 11 : 141, ic. 1939.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 110, 181, ic. 1943.

Wollenweber, Fus. del. 396–400, 404, 405, 418–421, 1029, 1031–1033, 1194.

Conidia scattered in the mycelium, in false heads, in sporodochia or pionnotes, brownish white to clayish yellow in mass, or tinged with the colour of the stroma. Stroma leathery, green to dark blue. Macroconidia almost cylindrical-fusiform, slightly curved, rounded at both ends, or tapering and bluntly conical, base with a scarcely perceptible papilla oblique to the longitudinal axis of the spore, seldom subpedicellate, 3–(3–5)-septate ; 0-septate 11×4 (6–17×3–5), 1-septate 17×4·1 (11–25×3–5), 3-septate 32×5·2 (23–45×4–6), 4-septate 39×5·1 (34–45×4–6). Chlamydospores terminal and intercalary, brownish, globose or pyriform, 1-celled 8·3 (6–10), 2-celled 13×8 (10–15×5–10).

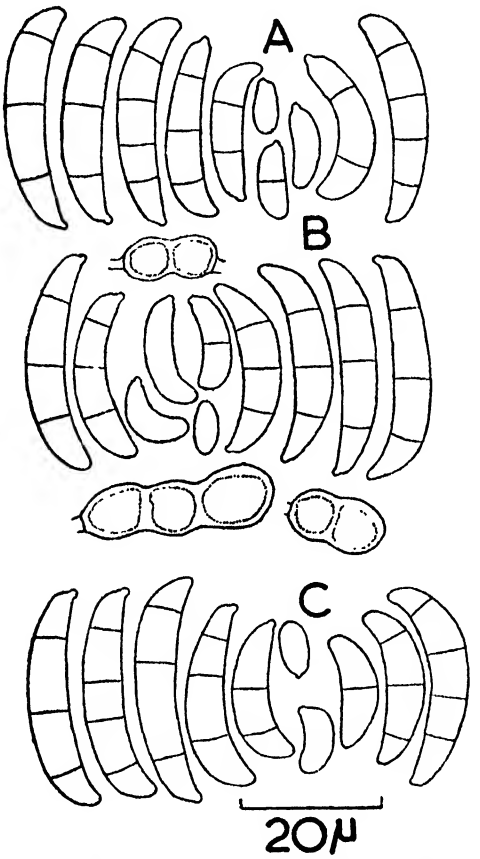

Fig. 11. *Fusarium solani*: conidia and chlamydospores from *A*, 10 days old culture on oatmeal agar; *B*, 10 days old culture on potato dextrose agar; *C*, 21 days old culture on samo medium.

Growth on Media.

On potato dextrose agar growth was fluffy with white aerial mycelium; stroma was cream (9 D 2) coloured; sporodochia of a cream to lichen green (26 A 4) colour developed in old cultures. On oatmeal agar growth was adpressed with no aerial mycelium; sporodochia and pionnotes were produced: these were of an Italian straw (11 D 2) colour in the beginning, later being tinged with Corydalis Gr (19 B 4) to Chrysolite Gr (19 K 3) due to the colour of the stroma. On lupin stems growth was white and fluffy with good development of sporodochia of a cream colour.

On steamed rice, the mycelium was white, later becoming Sirocco (14 B 2) to Buckskin (14 A 6) coloured.

Measurements of Conidia.

Oatmeal agar, 30 days old:

0-septate	13×4·1	mostly 9–14×3·3–4·2	(7–17×3–5) .. 14%
1-septate	16×4·3	mostly 11–22×3·3–4·9	(11–24×3–5) .. 9%
2-septate	24×4·8	mostly 21–29×4·1–5·8	(18–34×3–6) .. 4%
3-septate	31×5·1	mostly 26–37×4·1–5·8	(23–42×4–6) .. 73%
4-septate	40×5·2	.. ..	.. .. rare.
5-septate	47×5·4	.. ..	.. .. rare.

Potato dextrose agar, 21 days old:

0-septate	9×3·9	mostly 8–12×3·3–4·2	(6–15×3–5) .. 4%
1-septate	18×3·9	mostly 13–22×3·3–4·2	(11–25×3–5) .. 3%
2-septate	21×4·6	mostly 18–25×4·1–4·9	(16–29×3–6) .. 4%
3-septate	33×5·3	mostly 28–39×4·9–5·8	(24–45×4–6) .. 87%
4-septate	38×5	(34–45×4–6) ..	.. .. 2%
5-septate	45×5·2	.. ..	.. .. rare.

Average of the above measurements:

0-septate	11×4	mostly 8–14×3·3–4·2	(6–17×3–5)
1-septate	17×4·1	mostly 11–22×3·3–4·9	(11–25×3–5)
2-septate	23×4·7	mostly 18–29×4·1–5·8	(16–34×3–6)
3-septate	32×5·2	mostly 26–39×4·1–5·8	(23–45×4–6)
4-septate	39×5·1	(34–45×4–6)	
5-septate	46×5·3		

F. solani (Mart.) App. et Wr. v. *Martii* (App. et Wr.) Wr.

Wollenweber, Z. Parasitenk., 3 : 451, 483. 1931.—Wollenweber & Reinking, Die Fusarien, p. 136, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 37. 1935.—Bugnicourt, F., Encyclopedie mycol., 11 : 145, ic. 1939.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 110, 182. 1943.

Wollenweber, Fus. del. 411–414, 1034, 1195, 1196.

Conidia longer and thinner than *F. solani*, less curved in the middle than at the apex, base papillate, sometimes foot-celled, mostly 3-4 (5)-septate, microconidia 0–2-septate, scattered in the aerial mycelium; 0-septate 14×3·8 (9–17×3–5), 1-septate 19×4·1 (14–25×3–5), 3-septate 39×5 (28–54×4–6), 4-septate 44×5·1 (34–49×4–6). Conidia in mass brownish white, ivory yellow to dark brown, or tinged with the colour of the stroma. Stroma greenish blue, leather brown or coffee brown. Chlamydospores as in *F. solani*, 11×9 (8–15×6–12).

Growth on Media.

On potato dextrose agar growth was loosely fluffy and white with abundant development of sporodochia, somewhat coalesced to form a pionnotal layer; colour of sporodochia was Long beach (12 B 4). On oatmeal agar growth was adpressed with no aerial mycelium except at the top and the bottom of the slant, where aerial mycelium was white; sporodochia of an ivory (10 B 2) colour developed in abundance, coalescing to form a pionnotes. On Richard's agar the mycelium was fluffy, white or with a slightly yellowish tinge, forming a velvetty mat on the agar surface; sporodochia and pionnotes were not produced, but the stroma was well-developed and of an amber white (11 C 1) to Ecru-beige (11 C 2) colour;

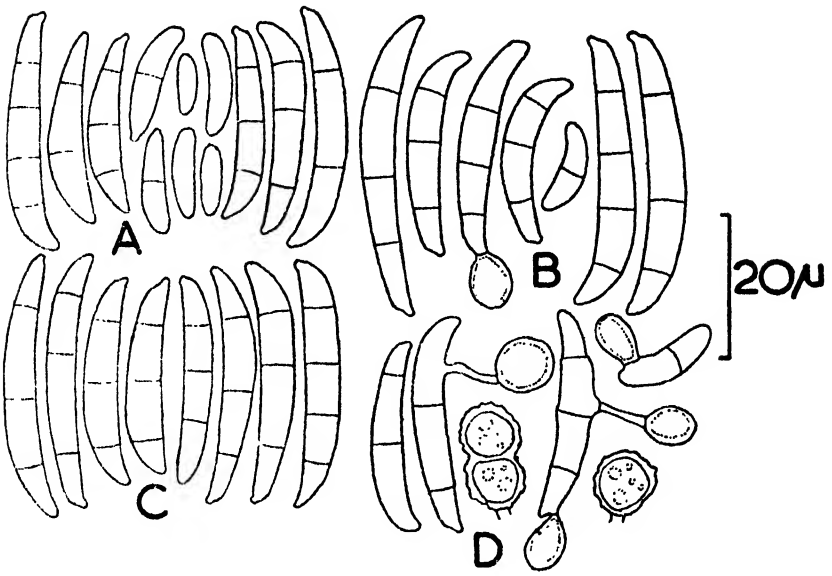

FIG. 12. *Fusarium solani* v. *Martii*: conidia and chlamydospores from *A*, 10 days old culture on oatmeal agar; *B*, 35 days old culture on same medium; *C*, 10 days old culture on potato dextrose agar; *D*, 49 days old culture on same medium.

the substratum was coloured primrose yellow (10 J 4) in the beginning, later deepening into Samovar (12 K 7), Hazel (13 J 9) and Coffee (15 A 11). On lupin stems the mycelium was white and fluffy; sporodochia of a cream (9 D 2) to maple (11 E 4) colour were produced in abundance. On steamed rice the mycelium was fluffy, short and felt-like and the colours developed were: Drab (14 B 5) to Beaver (15 A 6).

Measurements of Conidia.

Oatmeal agar, 33 days old:

0-septate 14×3·9 mostly 13–15×3·3–4·2 (11–17×3–5)	.. 17%
1-septate 19×4·2 mostly 16–22×4·2 (14–25×3–5)	.. 15%
2-septate 33×4·4 (18–40×4-5)	.. 3%
3-septate 39×4·9 mostly 33–44×4·9 (29–54×4–6)	.. 40%
4-septate 43×5 mostly 41–47×5·0 (34–49×4–6)	.. 25%

Potato dextrose agar, 10 days old:

0-septate 13×3·5 mostly 11–14×3·3–4·2 (9–15×3–5)	.. 28%
1-septate 19×3·9 mostly 18–22×3·3–4·2 (14–22×3–5)	.. 21%
2-septate 32×4·9 mostly 29–35×4·2–4·9 (24–35×4–6)	.. 7%
3-septate 38×5·1 mostly 33–42×4·9–5·8 (28–49×4–6)	.. 44%

Lupin stems, 10 days old:

0-septate 14×3·9 mostly 13–15×3·3–4·2 (11–17×3–5)	.. 32%
1-septate 20×4·2 mostly 18–22×4·2 (14–24×3–5)	.. 4%
3-septate 39×5·1 mostly 36–44×4·9 (29–50×4–6)	.. 61%
4-septate 45×5·1 mostly 43–47×4·9 (41–49×4–6)	.. 3%

Average of the above measurements:

0-septate 14×3·8 mostly 11–15×3·3–4·2 (9–17×3–5)
1-septate 19×4·1 mostly 16–22×3·3–4·2 (14–25×3–5)
2-septate 33×4·7 mostly 29–35×4·2–4·9 (18–40×4–6)
3-septate 39×5·0 mostly 33–44×4·9–5·8 (28–54×4–6)
4-septate 44×5·1 mostly 41–47×5·0 (34–49×4–6)

F. solani (Mart.) App. et Wr. v. *minus* Wr.

Wollenweber, Ann. mycol., 15 : 55. 1917.—Saccardo, Syll. Fung., 25 : 978. 1931.—Reinking & Wollenweber, Philip. J. Sci., 32 : 206, ic. 1927.—Wollenweber, Z. Parasitenk., 3 : 464. 1931.—Wollenweber & Reinking, Die Fusarien, p. 134, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 38. 1935.—Bugnicourt, F., Encyclopedie mycol., 11 : 133, ic. 1939.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 110, 186. 1943.

Wollenweber, Fus. del. 401–403, 630.

Differs from *F. solani* in having smaller macroconidia, mostly 3-septate. Conidia 0-septate 11×3·8 (4–20×3–5), 1-septate 16×4 (11–22×3–5), 3-septate 30×4·6 (20–44×4–6), 4-septate 31×4·8. Chlamydospores terminal or intercalary, smooth or verrucose, 1-2-celled, in chains or in clusters, 1-celled 7·8 (6–9), 2-celled 12×8 (11–14×6–10).

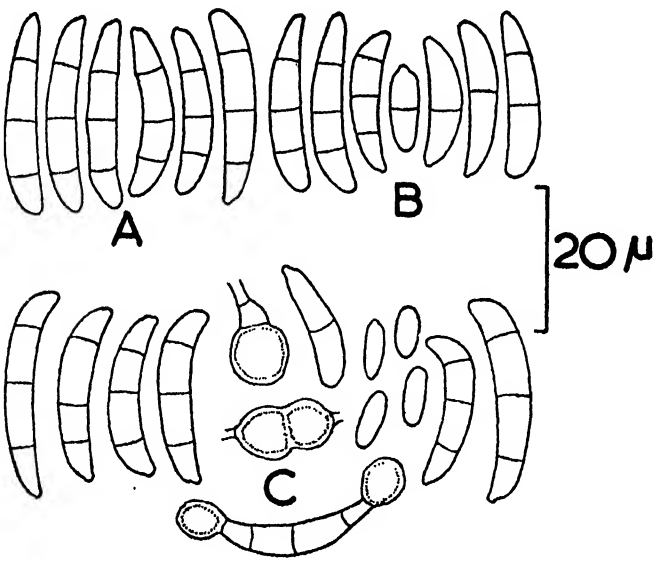

FIG. 13. *Fusarium solani* v. *minus*: conidia and chlamydospores from *A*, 21 days old culture on oatmeal agar; *B*, 10 days old culture on potato dextrose agar; 35 days old culture on same medium.

Growth on Media.

On potato dextrose agar growth was adpressed with no aerial mycelium; sporodochia of a dull cream (9 D 2) to Smokegrey (28 A 2) or gnaphalium green (28 A 4) colour developed in abundance; at the bottom of slants there was good development of a pionnotal layer of a Dewkiss (29 C 3) colour. On oatmeal agar also the growth was adpressed, with good development of sporodochia and pionnotes of an Old ivory (12 C 3) to Grain (13 B 5) colour. On lupin stems, the mycelium was short and fluffy, white to pale yellow in colour, with sporodochia

of a cream (9 D 2) colour. On steamed rice the mycelial growth was white, fluffy and felt-like with development, in old cultures, of the following colours: Gravel (13 A 4), Slate Gy (14 A 2), Dust (14 B 4) and Beaver (15 A 6).

Measurements of Conidia.

Oatmeal agar, 30 days old:

0-septate	11×3·5	mostly 9–13×3·3–4·2 (5–15×3–5) .. 13%
1-septate	14×3·9	mostly 11–17×3·3–4·2 (11–20×3–5) .. 10%
2-septate	20×4·3	mostly 18–24×4·2 (16–25×4-5) .. 4%
3-septate	30×4·4	mostly 24–34×4·2–4·9 (20–37×4-5) .. 73%
4-septate	32×4·7	.. .. rare.

Potato dextrose agar, 21 days old:

0-septate	10×3·7	mostly 8–12×3·3–4·2 (4–15×3–5) .. 10%
1-septate	17×4·2	mostly 14–20×4·2 (11–22×3–5) .. 9%
2-septate	22×4·3	mostly 19–24×4·2 (18–25×4–5) .. 10%
3-septate	28×4·7	mostly 24–32×4·2–4·9 (21–35×4–6) .. 71%
4-septate	28×4·9	.. .. rare.

Lupin stems, 21 days old:

0-septate	13×4·1	mostly 9–17×4·2 (8–20×3–5) 18%
1-septate	16×4	mostly 13–20×3·3–4·2 (11–22×3–5) .. 13%
2-septate	20×4·1	mostly 15–25×3·3–4·2 (13–29×3–5) .. 5%
3-septate	32×4·7	mostly 28–37×4·2–4·9 (26–44×4–6) .. 64%
4-septate	33×4·7	.. .. rare.

Average of the above measurements:

0-septate	11×3·8	mostly 8–17×3·3–4·2 (4–20×3–5)
1-septate	16×4	mostly 11–20×3·3–4·2 (11–22×3–5)
2-septate	21×4·2	mostly 15–25×4·2 (13–29×3–5)
3-septate	30×4·6	mostly 24–37×4·2–4·9 (20–44×4–6)
4-septate	31×4·8	

F. solani (Mart.) App. et Wr. v. *striatum* (Sherb.) Wr.

Wollenweber, Z. Parasitenk., 3 : 451, 483, ic. 1931.—Wollenweber & Reinking, Die Fusarien, p. 135, ic. 1935; Die Verbreitung der Fusarien in der Natur, p. 38. 1935.—Wollenweber, Zbl. Bakt., Abt. II, 106 : 110, 187, ic. 1943. Wollenweber, Fus. del. 406, 1030.

The fungus has characteristics intermediate between *F. solani* and *F. javanicum*. Sporodochia small, sometimes forming pionnotes pale in colour, or tinged with the colour of the stroma. Stroma blue green, olive or sepia brown. Conidia mostly 3 (0–5)-septate, more or less pedicellate; 0-septate 13×3·7 (8–20×2–5), 1-septate 24×4·2 (13–30×3–5), 3-septate 34×4·6 (24–47×4-5). Chlamydospores 1-celled 8·5 (6–10), 2-celled 13×8·5 (11–17×7–10).

Growth on Media.

On potato dextrose agar the mycelium was pale white and slightly fluffy, forming a mat over the agar surface; at the place of the inoculation sporodochia of a Smokegrey (28 A 2) colour developed even in young cultures; stroma was coloured Italian straw (11 D 2) to Arizona (13 E 6). On oatmeal agar aerial

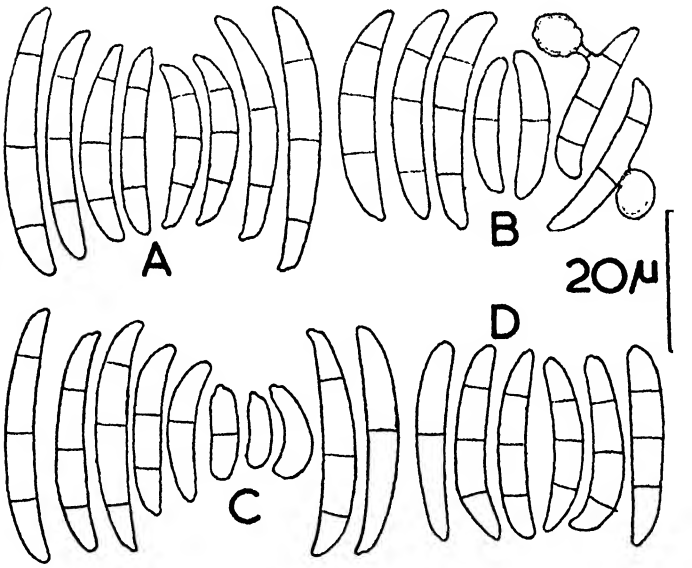

FIG. 14. *Fusarium solani* v. *striatum*: conidia from *A*, 10 days old culture on oatmeal agar; *B*, 35 days old culture on same medium; *C*, 7 days old culture on potato dextrose agar; *D*, 21 days old culture on same medium.

mycelium was absent; sporodochia of a New silver (11 B 1) colour were produced; stroma was coloured Italian straw (11 D 2). On Richard's agar the mycelium was fluffy and felt-like, with sporodochia of a cream (9 D 2) colour. On lupin stems aerial mycelium was sparse, but when present was of a flesh (11 A 2) or New silver (11 B 2) colour; sporodochia were cream to flesh coloured. On steamed rice the mycelium was white and felt-like and shades of white jade (10 A 2), Longechamps (5 A 9) and Rattan (11 K 6) developed.

Measurements of Conidia.

Oatmeal agar, 14 days old:

0-septate	11×3·2 mostly 9–14×2·4–3·4 (8–17×2–5)	.. 12%
1-septate	23×4·3 mostly 19–26×4·1–4·9 (13–29×3–5)	.. 13%
2-septate	27×4·3 mostly 24–29×4·1–4·9 (23–34×4-5)	.. 16%
3-septate	32×4·5 mostly 29–35×4·1–4·9 (26–40×4-5)	.. 59%

Potato dextrose agar, 21 days old:

0-septate	14×3·9 mostly 9–15×3·3–4·2 (8–19×2–5)	.. 19%
1-septate	23×4·2 mostly 21–27×4·2 (16–29×4-5)	.. 21%
2-septate	30×4·3 mostly 28–32×4·1–4·9 (24–39×4-5)	.. 22%
3-septate	35×4·5 mostly 31–39×4·1–4·9 (26–44×4-5)	.. 38%

Lupin stems, 21 days old:

0-septate	15×3·9 mostly 11–17×3·3–4·2 (9–20×3–5)	.. 2%
1-septate	25×4·2 mostly 23–27×4·2 (19–32×4-5)	.. 21%
2-septate	29×4·4 mostly 26–32×4·2–4·9 (23–34×4-5)	.. 26%
3-septate	35×4·7 mostly 31–39×4·2–4·9 (24–47×4-5)	.. 51%

Average of the above measurements:

0-septate 13×3·7 mostly 9–17×2·4–4·2 (8–20×2–5)
1-septate 24×4·2 mostly 19–27×4·2 (13–30×3–5)
2-septate 29×4·3 mostly 24–32×4·1–4·9 (23–39×4–6)
3-septate 34×4·6 mostly 29–39×4·1–4·9 (24–47×4-5)

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SCATTERING OF ELECTRONS AND CONTRAST IN THE ELECTRON-MICROGRAPHS OF SHADOW-CAST SPECIMENS.

By A. K. CHAUDHURI (*Formerly Research Fellow, N.I.S.I.*), *Department of Mathematics, Indian Institute of Technology, Kharagpur.*

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INTRODUCTION.

The electron-microscope has made it possible to visualise extremely small objects of diameter of the order of 10 Å diameter, by virtue of its high resolving power. However the realisation of this goal is dependent on adequate contrast or electron-scattering power of the specimen. The possibility of this limitation was first pointed out by L. Marton (1936). In electron-microscope practice, the objects are usually mounted on very thin films of collodion, formvar, etc. The contrast in the microscope image depends on the mass-distribution of the specimen, the denser portions scattering more electrons than the lighter ones.

The eye cannot distinguish between two regions which differ in brightness by less than a certain minimum amount which is usually taken as 10% (Zworykin *et* al., 1945). Hence a particle will not be detected unless it has enough mass to scatter out at least 10% more electrons than the supporting film. This contrast difficulty is very serious in the study of minute biological objects such as viruses. It is difficult to see these organisms although their dimensions (100 Å) are greater than the resolution of the microscope. This is caused by the fact that their scattering power is of the same order as the supporting film and consequently in the image contrast is very poor.

In order to overcome this difficulty, the scattering from the substrate has to be diminished and that from the particle increased at the same time. The first requirement is fulfilled by making the substrate of material of the lowest mean density and atomic number, and as thin as possible, so that it is just strong enough to stand the electron beam. The method of preparing very thin films of formvar, aluminium, beryllium, etc. (20–30 Å thick) for this purpose has been described in literature (Cosslett, 1948; Hast, 1947, 1948).

The electron scattering power of the specimen can be artificially increased by depositing heavy atoms on its surface. The technique of vacuum evaporation has been developed for this purpose. Müller (1942) in Germany first utilised this technique to measure the heights of electron-microscopic objects. Later in 1944 Williams and Wyckoff introduced the technique of shadow-casting in electron-microscopy. The particle is exposed obliquely to an atomic beam of heavy metal which is evaporated under high vacuum (10^{-4} to 10^{-5} mm. of Hg). That side of the object which faces the oncoming atoms gets a layer of the metal attached to it while no metal falls in the region just behind the particle. The extent of this clear region depends on the height of the particle and its position with respect to the atom-source during deposition. The clear portions, when viewed later on the negative electron-micrograph, appear like shadows and give the image the appearance of a three dimensional object illuminated by a beam of light whose direction is the same as that of the shadowing atoms.

The amount and the nature of element used for shadowing has to be selected with great care. If the shadowing metal is too much it will distort the actual shape and cause serious errors in the size determinations. On the other hand, too little metal vapour will not provide adequate contrast. In this paper we have calculated the thickness of metal needed to produce the desired contrast for different elements.

Theoretical Considerations.

In Fig. 1, a parallel beam of electrons is incident on the object. On meeting the object the electrons are scattered and emerge out as a divergent beam. The electrons making angles up to say θ with the optic axis are allowed by the objective lens aperture and focussed by the lens on to the image plane. The optimum

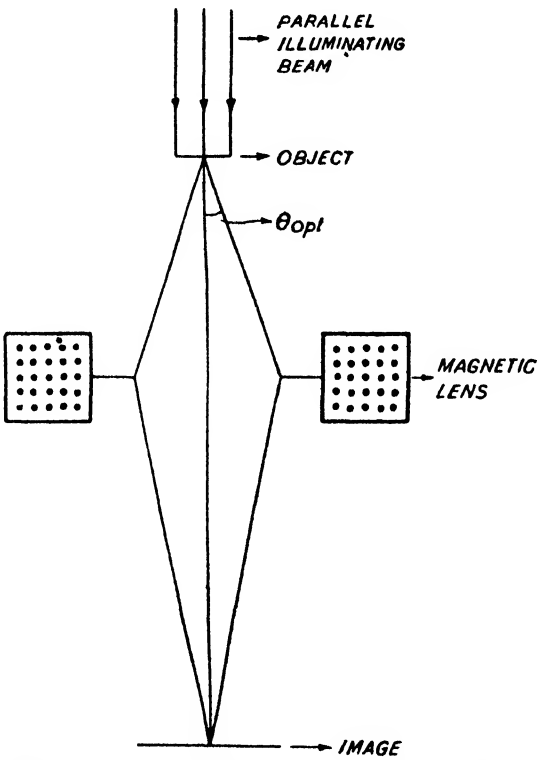

FIG. 1. IMAGE FORMATION BY AN ELECTRON-MICROSCOPIC OBJECTIVE.

aperture angle for best resolution considering the combined effect due to spherical aberration and diffraction is given by

$$\theta_{\text{opt}} = \left(\frac{\lambda}{2Cf}\right)^{\frac{1}{4}} \quad .. \quad .. \quad .. \quad .. \quad (1)$$

where λ = Broglie wavelength of the image forming electrons.
C = spherical aberration constant, and
f = focal length of the objective lens.

According to Rebsch (1938), the lowest obtainable value of C can be estimated to be ·25. For an objective with very short focal length of 1 mm. and for electrons of 50 kV energy we have

$$\theta_{\text{opt}} = 10^{-2} \text{ radians.}$$

However, in practice the conditions are not so ideal and practical values of the aperture angle are usually of the order of 10^{-3} or less.

The incident electrons on encountering the specimen may be scattered in three different ways namely—(1) elastic scattering with no energy change, but only with direction change, (2) inelastic scattering resulting in excitation or ionization of the atom, and (3) scattering by free electrons in the case of a metal. If we suppose that the total scattering cross-section is the sum of the three individual scattering cross-sections (Marton, L. and Schiff, L. I., 1941), we have

$$\sigma = \sigma_e + \sigma_i + \sigma_f \quad .. \quad .. \quad .. \quad .. \quad (2)$$

where σ_e = elastic scattering cross-section,
σ_i = inelastic scattering cross-section, and
σ_f = cross-section of scattering by free electrons.

Considering the layer of object of thickness t to be divided into infinitesimal layers of thickness dt, it can be supposed that the electrons are scattered singly by each such layer. It can then be shown that if i_0 = the incident beam current and i_t = transmitted beam current, we have the relation

$$\frac{i_t}{i_0} = e^{-Nt\sigma(\theta)} \quad .. \quad .. \quad .. \quad .. \quad (3)$$

where N = the number of atoms per unit volume of the specimen.

The contrast effect in the image will evidently be determined by the excess of the incident beam current over the transmitted beam current expressed as a fraction of the incident beam current, i.e. by the quantity

$$\frac{i_0 - i_t}{i_0}.$$

Denoting this quantity by g we obtain with the help of Eqn. (3)

$$g = 1 - e^{-Nt\sigma(\theta)} \quad .. \quad .. \quad .. \quad .. \quad (4)$$

Solving for t we get

$$t = \frac{ln\left(\frac{1}{1-g}\right)}{N\sigma(\theta)} \times 10^8 \text{ Angstroms.}$$

Replacing N by $N = \frac{N_A \rho}{A}$,

where N_A = Avogadro's number
ρ = density and A = the atomic weight of the material of the specimen; we obtain finally for t

$$t = \frac{Aln\left(\frac{1}{1-g}\right)}{\rho N_A \sigma(\theta)} \times 10^8 \text{ Angstroms} \quad .. \quad .. \quad .. \quad (5)$$

The above formula is correct so long as multiple scattering is neglected. This is usually justified in shadow-casting for electron-microscopy since the thicknesses of deposits used are extremely small. This point will be discussed later.

Elastic Scattering Cross-Section.

The differential cross-section of scattering per unit solid angle for fast electrons from a consideration of the relativistic Schrödinger's equation, as found out by Williams (1939), is

$$\frac{d\sigma}{d\omega} = \frac{z^2e^4}{4m_0^2\xi^2v^4} \cdot \frac{1}{\sin^4\frac{\theta}{2}} \quad .. \quad .. \quad .. \quad .. \quad (6)$$

where m_0 = rest mass of the electron,

v = velocity of the incident electron,

$$\xi = \left(1-\frac{v^2}{c^2}\right)^{-\frac{1}{2}} \text{ and}$$

$d\omega$ = element of solid angle.

Hence the total cross-section for elastic scattering is given by

$$\sigma_e(\theta) = \frac{z^2e^4}{4m_0^2\xi^2v^4}\int_\theta^\pi\int_0^{2\pi} \frac{\sin\theta\, d\theta\, d\phi}{\sin^4\frac{\theta}{2}}$$

$$= \frac{4\pi z^2e^4}{m_0^2\xi^2v^4}\left(\frac{1}{\theta^2}-\frac{1}{4}\right) \quad .. \quad .. \quad .. \quad .. \quad .. \quad (7)$$

In the above formula the approximation $\sin\theta = \theta$ has been used after integration. This is quite justified in view of the very small angles used. Since θ is small we can neglect the upper limit and write finally

$$\sigma_e(\theta) = \frac{4\pi z^2e^4}{m_0^2\xi^2v^4} \cdot \frac{1}{\theta^2} \quad .. \quad .. \quad .. \quad .. \quad .. \quad (8)$$

From the above expression it is seen that $\sigma_e(\theta)$ tends to infinity as θ tends to the value zero. This happens because we have neglected the screening effect of the atomic electrons which becomes extremely important for very small angles. In fact the above approximation is valid only up to a certain minimum angle θ_{min}. To determine the cross-section for angles $\theta < \theta_{min}$ we must take the effect of screening into account. In the wave treatment the scattering through an angle θ depends on the field at distances of the order of $\frac{\lambda}{\theta}$,

where

$$\lambda = \left(\frac{\hbar}{m_0\xi v}\right) = \frac{1}{2\pi} \text{ times}$$

the de Broglie wavelength of the electron. Now the dimension of the Coulombian field can be taken as

$$a = a_0z^{-\frac{1}{3}} = z^{-\frac{1}{3}}\left(\frac{\hbar^2}{m_0e^2}\right)$$

where a_0 = radius of the Bohr orbit of the hydrogen atom. So that up to the distance a the effect of screening can be neglected. From the above considerations it is clear that the cut-off angle in the wave treatment is approximately

$$\theta_{min} = \frac{\lambda}{a} \quad .. \quad .. \quad .. \quad .. \quad .. \quad (9)$$

Substituting this value of θ_{min} in Eqn. (8) we obtain for the total cross-section of elastic scattering for angle $\theta = \theta_{min}$, as

$$\sigma_e(\theta_{min}) = \frac{1}{\pi}\xi^2\lambda^2 z^{4/3} \quad .. \quad .. \quad .. \quad .. \quad (10)$$

To find out the contribution to the cross-section for angles θ less than θ_{min}, William's (1939) formula for the shielded field can be used;

$$\frac{d\sigma}{d\omega} = \frac{4z^2e^4}{m_0^2\xi^2v^4} \cdot \frac{1}{\theta^4\left(1+\frac{\lambda}{a^2\theta^2}\right)} \quad .. \quad .. \quad .. \quad .. \quad (11)$$

Integrating this expression with respect to ϕ from 0 to 2π and with respect to θ from θ to θ_{min}. we obtain

$$\sigma_e(\theta) - \sigma_e(\theta_{min}) = \frac{4\pi z^2e^4}{m_0^2\xi^2v^4}\frac{1}{\theta_{min}^2}\left\{\frac{\theta_{min}^2(\theta_{min}^2-\theta^2)}{\theta_{min}^2+\theta^2}\right\} \quad .. \quad .. \quad .. \quad (12)$$

where $\frac{\lambda}{a}$ has been put equal to θ_{min}.

Hence

$$\sigma_e(\theta) - \sigma(\theta_{min}) < \sigma(\theta_{min}) \cdot \frac{1}{2}(\theta_{min}^2 - \theta^2) \cdot \quad .. \quad .. \quad .. \quad (13)$$

From the above it is evident that the contribution to the cross-section by scattering through angles $\theta < \theta_{min}$ is negligible. Hence we can take equation (10) as the total elastic cross-section for angles less than θ_{min}. In electron-microscopy the above condition is always realised in practice.

Inelastic Scattering.

The atomic electrons will give rise to independent scattering as a result of which they are either raised to a higher level or ejected out of their orbits. The intensity of this inelastic scattering can be shewn to be of the order of $\frac{1}{z}$ times the elastic scattering (Williams, E. J., 1940). The effective lower limit of the angle of scattering is $\frac{\lambda}{a'}$ where a' represents the dimension of the orbit of the atomic electrons. This cut-off angle is of the same order as the cut-off of elastic scattering due to shielding. Also the maximum angle through which the incident electron can be scattered by the atomic electrons is of the order of $\left(\frac{2}{\xi}\right)^{\frac{1}{2}}$. However this can be neglected in comparison with $\frac{\lambda}{a'}$. Hence the inelastic scattering cross-section can be approximately taken to be

$$\sigma_i = \frac{1}{z}\sigma_e \quad .. \quad .. \quad .. \quad .. \quad .. \quad (14)$$

This can be neglected in comparison with σ_e for the metals usually used in shadow-casting.

Scattering by Free Electrons.

Marton and Schiff (1941) have calculated the cross-section of scattering by conduction electrons. According to them

$$\sigma_f = 8\pi\nu \left(\frac{e^2}{m\xi v^2}\right)^2 \left[\frac{3}{4\theta_4\theta} - \frac{3}{8\theta_4^2} + \frac{\theta}{16\theta_4^3}\right] \quad .. \quad .. \quad (15)$$

for $\theta < 2\theta_4$

where

$$\theta_4 = \lambda\left(\frac{3\nu N_A \rho}{8\pi A}\right) \quad .. \quad .. \quad .. \quad .. \quad (16)$$

where ν = the number of free electrons per atom.

Multiple Scattering.

Relation (5) has been deduced on the supposition that only single scattering takes place. Hence it is important to know at what thicknesses multiple scattering sets in. Due to multiple scattering the intensity distribution per unit solid angle can be approximately given by a Gaussian curve of the form (Zworykin *et al.*, 1945)

$$G(\theta) = \frac{1}{\pi\overline{\overline{\theta^2}}} e^{-\frac{\theta^2}{\overline{\overline{\theta^2}}}} \quad .. \quad .. \quad .. \quad .. \quad (17)$$

Where $\overline{\overline{\theta^2}}$ is the mean square deflection and is given by (Williams, E. J., 1939)

$$\overline{\overline{\theta^2}} = k \ln \frac{k}{\theta^2_{\min}} \quad .. \quad .. \quad .. \quad .. \quad (18)$$

For $\theta_{\min}$ Eqn. (9) must be used and

$$k = \frac{4\pi N_A \rho t}{A}\left(\frac{ze^2}{\hbar v}\right)^2 \cdot \lambda^2 \quad .. \quad .. \quad .. \quad .. \quad (19)$$

Integrating the above expression with respect to ϕ from 0 to 2π and with respect to θ from 0 to θ we get the fraction of incident current that is scattered back into the aperture due to multiple scattering as

$$\frac{i_m}{i_0} = \frac{1}{\pi\overline{\overline{\theta^2}}} \int_0^{2\pi}\int_0^{\theta} e^{-\frac{\theta^2}{\overline{\overline{\theta^2}}}} \theta\, d\theta\, d\phi \quad .. \quad .. \quad .. \quad (20)$$

$$\left(1 - e^{-\frac{\theta^2}{\overline{\overline{\theta^2}}}}\right) \cong \frac{\theta^2}{\overline{\overline{\theta^2}}}$$

As long as this quantity is small compared to $e^{-\sigma Nt}$ we can suppose that single scattering alone gives a sufficiently true account. For the thickness usually used in shadow-casting for electromicroscopy this condition is satisfied. As for instance for gold we have for $\theta = 10^{-3}$ radians, and accelerating voltage of 50 kV

$$\frac{\theta^2}{\overline{\overline{\theta^2}}} / e^{-\sigma Nt} \leq 1{\cdot}9 \times 10^{-4} \quad .. \quad .. \quad .. \quad .. \quad (21)$$

for $\rho t \leq 10^{-5}$ i.e. for $t \leq 50$ Å

TABLE 1.

Calculated values of elastic (σ_e) and free electron (σ_f) scattering cross-sections and the corresponding thicknesses t_1 and t_2 for different metals to produce 20% contrast in the image for 50 kV electrons and θ assumed to be 10^{-3} radians.

Metal.	$\sigma_e \times 10^{17}$ cm.^{2}	t_1 Å	$\sigma_f \times 10^{17}$ cm.^{2}	$\sigma \times 10^{17}$ cm.^{2}	t_2 Å
Cr ..	·76	36·3	·38	1·14	24·3
Ni ..	·93	26·8	·60	1·53	16·7
Pd ..	1·81	17·9	·41	2·22	14·9
Ag ..	1·86	20·1	·43	2·29	16·4
Pt ..	3·66	9·2	·41	4·07	8·3
Au ..	3·72	10·1	·43	4·15	9·0
U ..	4·48	10·4	·73	5·21	8·9

This is very small. Hence it is seen that multiple scattering can be neglected. A better approximation can be obtained by applying Goudsmit and Saunderson's (1940) theory of multiple scattering.

PRACTICAL APPLICATION.

The thickness of deposit of various metals required to produce a contrast of 20% in the shadow, has been calculated. In these calculations the effect of inelastic scattering has been totally neglected. The results of the calculations have been summarised in Table I.

The values of σ_e, σ_f and σ have been given in the 2nd, 4th and 5th columns respectively of Table I, for different elements, for 50 kV electrons and for $\theta = 10^{-3}$ radians. The third column gives the thicknesses of the metals required to produce 20% contrast, calculated from formula (5) taking only the elastic scattering cross-section. The last column gives the thickness for the same contrast taking the free electron scattering also into account. It is seen that the effect of this on the thickness of deposit is small in the case of the heavy elements, whereas it is appreciable in the case of the lighter elements.

Figs. 2 and 3 show the contrast diagrams for two of the most frequently used metals in shadow-casting namely gold and chromium. These diagrams are plots of equation (5) with g in per cent taken as abscissa and the corresponding deposit thickness in Angstroms taken as ordinate. For gold the curve has been drawn taking the free-electron scattering also into consideration. For chromium two separate curves have been drawn: the continuous curve corresponds to the case where only elastic scattering is considered, while the dotted one represents the case where the effect of conduction electrons has also been taken into account.

From the table it is seen that with metals of higher atomic weight, shadows of adequate contrast may be formed even with a very thin layer of the shadowing metal. Shadowing angles from $\tan^{-1}(1)$ to $\tan^{-1}(1/11)$ can be used depending on the nature of the particle to be investigated. The angle of shadowing determines the degree of relief of the image. For examining very small details large angle shadowing is required to bring out the necessary relief while for large objects small angles would suffice. If the background thickness of the deposit is t applied at

an angle $\tan^{-1}\frac{1}{b}$, the thickness of the deposit on the side of the particle directly, facing the metal is of the order of bt. So while shadowing care should be taken so that bt does not become comparable with the particle diameter. Hence for large angle shadowing, which is required to examine very fine details, the use of higher atomic weight elements is desirable such as gold, uranium, platinum, palladium, etc.

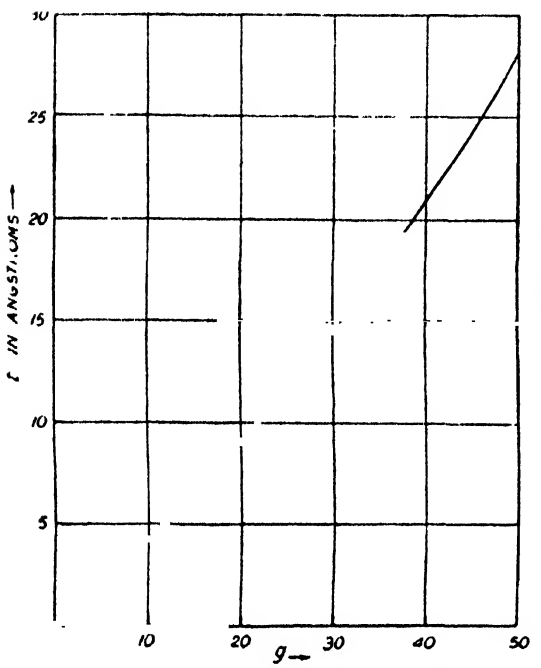

FIG. 2 CONTRAST DIAGRAM FOR GOLD

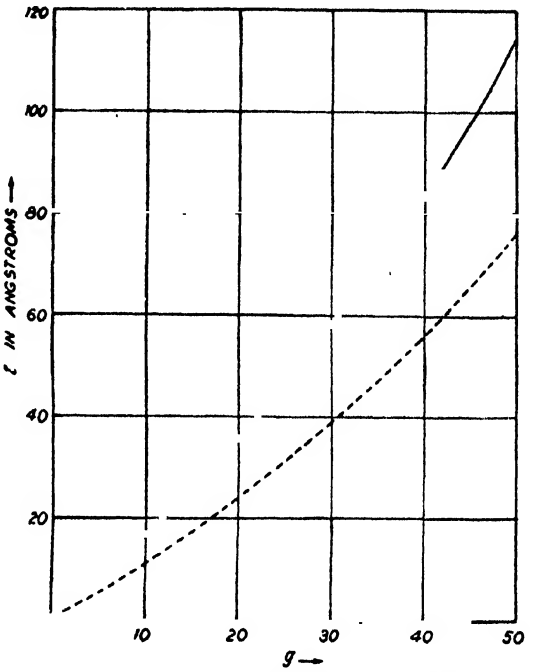

FIG. 3. CONTRAST DIAGRAM FOR CHROMIUM

The above considerations provide for a very good guide in shadowing electron-microscopic specimens. A large number of electron-micrographs were actually taken of specimens shadowed with different metals at varying thicknesses and it was found that the contrast in the shadows conforms well with the theoretical considerations. Some of these shadow micrographs have been reproduced in Figs. 4 and 5.

Figs. 4 (*a*), (*b*), (*c*) shew the electron-micrographs of gold-shadowed bacteria flexneri the thicknesses of the deposit being 5 Å, 8 Å and 15 Å respectively. From Fig. 2, the contrast in the shadow comes out respectively to be 6%, 20%, and 30·5%.

Figs. 5 (*a*), (*b*), (*c*), show the shadow micrographs of bacteria Shigella shigae which had been shadowed with chromium at thicknesses of 85 Å, 45 Å, and 23 Å respectively. From the dotted curve of Fig. 3 the contrast in the shadow comes out to be a little above 50%, 33%, and 195% while from the continuous curve it is 40·5%, 24%, and 13·5% respectively.

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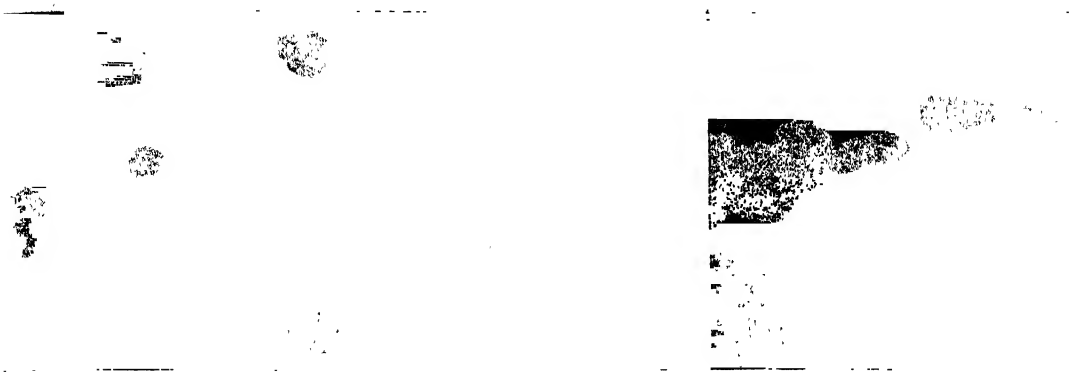


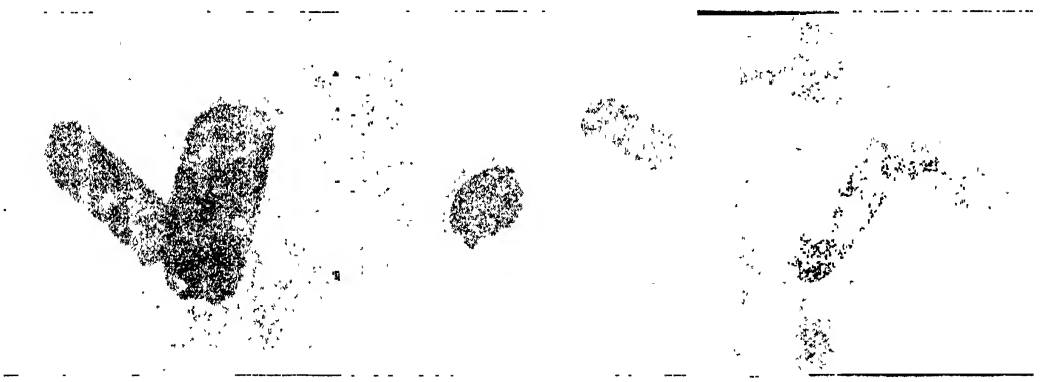
(*a*) (*b*) (*c*)

FIG. 4. Gold-shadowed Shigella flexneri.

(*a*) 5 Å of gold at an angle of $\tan^{-1}\frac{1}{11}$, ×15000.

(*b*) 8 Å of gold at an angle of $\tan^{-1}\frac{1}{7{\cdot}5}$, ×3500.

(*c*) 15 Å of gold at an angle of $\tan^{-1}\frac{1}{6}$, ×9850.



(*a*) (*b*) (*c*)

FIG. 5. Chromium-shadowed Shigella shigas.

(*a*) 23 Å of chromium at an angle of $\tan^{-1}\frac{1}{5{\cdot}5}$, ×11800.

(*b*) 45 Å of chromium at an angle of $\tan^{-1}\frac{1}{4{\cdot}4}$, ×11200.

(*c*) 85 Å of chromium at an angle of $\tan^{-1}\frac{1}{4}$, ×9700.

SUMMARY.

The part played by scattering of electrons in the formation of image by transmission type electron-microscopes has been discussed with special reference to shadow-cast electron-micrography. The thickness of deposit to produce desirable contrast in the image has been theoretically calculated for a number of metals like gold, chromium, palladium, etc., suitable for shadow-casting. A large number of specimens has been shadowed according to theoretical considerations and found to produce well perceptible shadows.

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TERTIARY POLLEN FROM LIGNITES FROM PALANA (EOCENE), BIKANER.

By A. R. Rao, *D.Sc., and* K. P. Vimal, *M.Sc., Department of Botany and Geology, Lucknow University, Lucknow.*

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Introduction.

The occurrence of at least ten different types of pollen grains in some small lignites from Palana had already been reported in 1950 (Rao and Vimal). Encouraged by these finds, one of us went to Palana and collected lignites at different levels from a seam about 20 ft. thick. This seam occurs at a place about 1½ miles from Palana Rly. station in the district of Bikaner, Rajasthan. The beds according to the Geological Survey of India definitely belong to the Eocene age (La Touche, 1897). Samples from a bed about three feet from the top (Bed 2), were macerated and examined. This examination revealed the occurrence of a number of microfossils like the oil bearing alga *Botryococcus Braunii*, small bits of cuticles of leaves and stems, pieces of wood, fungal and other kinds of spores, mycelia and pollen. At least twenty new types of pollen were found and their occurrence already reported (Rao and Vimal, 1951) and only these are being described in detail in the present paper. Samples from other beds are being macerated and a detailed and comprehensive description of these will be published in due course.

Material and Methods.

The material examined comes from Bed 2 which is about 3 ft. from the top of the seam which is about twenty feet in thickness. The material can be described as partly lignitic and partly peat. It is blackish in colour and very friable on drying. Pieces of yellow resin also occur associated with these lignites. The material not only contains loose pollen grains but also other microfossils, and even tiny pieces of wood.

The macerations of the lignites were done under bell jars inside a fume chamber. Before maceration the pieces were first heated in a Bunsen flame and then transferred to the macerating fluid. After about a week's treatment with only strong nitric acid the material was washed and treated with 10% solution of Potassium hydroxide for about two hours. After this, the material which settled down to the bottom of the tube was washed repeatedly with distilled water. The material was then spread out on the slides in Glycerine Jelly and covered with a cover slip. All possible precautions to prevent laboratory contamination with living spores and pollen were taken. Different samples from the same block were examined and it was found that they all contained the same types of microfossils and only such types as occurred in all the different slides and samples were studied. The microfossils were examined in transmitted light with the normal low and high power objectives of the microscope. The use of an oil immersion lens was not found necessary. Staining the microfossils was also tried but without success. The grains were measured and drawn as far as possible both in polar and equatorial views. The pollen grains were measured across in two planes at right angles to

each other in their polar views. In the equatorial view they have been measured along their pole to pole axis and the equatorial axis of the grain. These measurements are mentioned immediately after the respective views of the grain. Often the grains were allowed to roll over by gently moving the coverslip and the different views of the same grain were noted and sometimes even photographed. To make it easier for comparison, all grains as far as possible were drawn magnified to 1300 times and photographed at a magnification of 680. They are, however, reduced to 650 and 566 respectively in the illustrations of this paper. The photographs are all from untouched negatives.

Terminology.

In the detailed description of the pollen grains we have adopted the same terminology as has been used by Erdtman (1943) in his very valuable book.

Classification.

In classifying these pollens we have in general followed tentatively the classification of Wodehouse (1935) based upon colpae and pores. The grains with pores have also been grouped, according to Naumova's (1937) classification, into *Monoporosa*, *Diporosa*, *Triporosa*, etc. The term *Brachytrilistriate* has also been borrowed from Naumova's scheme to describe some kinds of tricolpate grains. Erdtman has recently (1947) classified the fossil spores on the basis of not only the above characters but also on the structural details of the grains. We have not been able to fully adopt this classification because some of the diagnostic characters are not clear in our types, still we have tried to place our grains in their proper places in the above classification also, as far as our observations permit.

Comparisons.

It will be readily admitted that comparison of fossil pollen with living material is a difficult problem. For one thing, we had no access to detailed or exhaustive literature on all kinds of living pollen. Secondly fossil pollen are subject to certain changes of shape, size and form during fossilisation. These two facts render our task of comparison very difficult and risky. It was therefore thought best to just describe the grains and not make ready comparisons. Yet as far as possible comparisons have been made when there has been close agreement between the living and fossil grains in form, dimensions, structural details and surface sculpturing. In this connection the important and invaluable books of Erdtman (1943) and Wodehouse (1935) proved our mainstay. Selling's excellent monograph on Hawaiian pollen (1947) was also very helpful.

Nomenclature.

We prefer to describe our fossil grains for the present as just types. These types, mentioned in this paper have also been serially numbered in continuation with those described in our previous paper (1950). We are not inclined to adopt a binomial nomenclature yet, because we feel that identification based only upon external characters of the pollen grains are not fully satisfactory. Besides, we do not know fully the pollen grains of all the living plants. This naturally limits the field and value of our comparisons. Any generic and specific nomenclature of these pollen based upon the comparison of the living with the fossil pollen, should preferably be supported by other evidences like leaf cuticles, wood bits, floral parts, seeds, etc. Till this is possible a comparison only with known living types seems to be the desirable course.

Conclusion.

The twenty different types of pollen described in this paper as also the ten different kinds, described in our previous note (Rao and Vimal, 1950) all come from lignitic beds of Palana which are regarded as Lower Eocene in age (La Touche, 1897). The large number of Angiosperm pollen grains seen in our material generally support this view. It has not been possible to compare all our pollen grains with living types. But pollen grains comparable to those of *Potamogeton*, *Betula* and *Tilia* have been described from the Green River Flora (Colorado, Utah., U.S.A.), which is Eocene in age (Wodehouse, 1933). Miss Cookson (1950) has also described the pollen of different species of *Proteacidites* from the Tertiary flora of Australia. Our collection shows a few pollen resembling some of the types described in the above two floras, and this lends further support to the Eocene age of the Palana lignites.

Such of the pollen grains as have been compared, appear to belong to the following families, Betulaceae (*Betula lenta, B. tortusa*) Fagaceae (*Quercus robur*), (*Q. agrifolia*), Aceraceae (*Acer negundo*) Proteaceae (*Proteacidites symphyonemoides*), Potamogetonaceae (*Potamogeton natans*) Tiliaceae (*Tilia americana*), Cornaceae (*Cornus amomum*), Pteridophytic spores are very rare and Conifer pollen appear to be absent.

Without being dogmatic about it we wish to draw attention to some significant points. The presence in the matrix of a large number of *Botryococcus Braunii*—a fresh water planktonic alga (Fritsch, 1935), and pollen comparable to those of *Potamogeton natans* and also the absence of any marine fossils suggest strongly that the lignitic beds were probably fresh-water deposits. The pollen of the various terrestrial types listed above must have been blown into this deposit. This is quite likely since most of these plants which are anemophilous produce large quantities of pollen.

Acknowledgement.

We are grateful to the Uttar Pradesh Government Scientific Research Grants Committee with whose financial assistance this investigation was carried out.

Description.

Aporosa.

Type No. 11. Polar view (Pl. XVII, fig. 1; Pl. XVIII, fig. 1), 25·0μ × 22·4μ, more or less spherical, Exine thin, 1·1μ, hyaline incompletely preserved, smooth, the body of the spore separated from the wall at places by 2·3μ. The absence of a pore and the presence of a triradiate mark shows that it is a Pteridophytic spore; colour brown.

Monoporosa. (Types 12 and 13 come also under *Monoporites* of Erdtman, 1947).

Type No. 12. Polar view (Pl. XVII, fig. 2; Pl. XVIII, fig. 2), round, 28·8μ in diameter, differentiated into an outer zone 3·5μ broad, lighter in colour and an inner zone 4·5μ broad and darker in colour. Exine smooth very thin, less than a micron in thickness. The simple central pore is slightly angular; brown. This type can be referred to *Psilomonoporites* of Erdtman (1947, p. 109).

Type No. 13. Polar view (Pl. XVII, fig. 3; Pl. XVIII, fig. 3), round, 35·5μ, in diameter, ektexine 1·5μ thick, smooth and hyaline, (seen partly peeled off in the illustrations). Intexine thin, 1·19μ in thickness, pore central, round; light brown. This type too can be referred to *Psilomonoporites* of Erdtman (1947). Types 12 and 13 resemble the pollen of Gramineae in having a single pore. But the thickened exine rim round the pore so characteristic of the grass grains (Erdtman, 1943, p. 56; Wodehouse, 1935, p. 304) is not found in our specimens.

Triporosa. (Types 14–18, come under *Triorites* of Erdtman, 1947).

Type No. 14. Polar view (Pl. XVII, fig. 4; Pl. XVIII, fig. 4) flat, triangular, 33·6μ × 35·2μ, pores three, one at each angle, aspidate, sides convex, exine 1·2μ thick, granular, hyaline; below the exine and extending from pore to pore is a thickening not seen in the photograph but shown shaded in the figure (2·2μ). This perhaps is not the intine but may

be a subexineous thickening like the one seen in *Alnus* (Wodehouse, 1935, p. 370) and regarded as very characteristic of the genus *Alnus*. A comparison between our specimen and *Alnus*, is not possible partly because of the difference in dimensions and partly because of the presence of more than three pores in *Alnus*. This type although resembling type 4 (Rao and Vimal, 1950, p. 84), differs from it in being smaller and having slightly convex sides; light yellow. This type can be referred to *Granulotriorites* of Erdtman (1947, p. 110).

Type No. 15. Polar view (Pl. XVII, fig. 5; Pl. XVIII, fig. 5) flat triangular, 36·8μ × 36·8μ, with straight sides; equatorial view narrowly elliptic. It is difficult to photograph the equatorial view as the grain does not rest in that position. Pores round, three, one at each angle 7·1μ in diameter slightly sunken 3·6μ deep. Exine smooth, 1·2μ thick, subexineous thickening 1·3μ in thickness, surface sculpture granular; yellow. This type too can be referred to *Granulo-triorites* of Erdtman (1947, p. 110).

Type No. 16. Grain flattened, triangular. Polar view (Pl. XVII, fig. 6; Pl. XVIII, fig. 6) equilateral, 34·5μ × 34·5μ. Pores three, one at each angle, exine 1·2μ thick, smooth, subexineous thickening present (2·4μ), surface reticulately sculptured; yellow. A comparison is possible between this grain and the pollen grain of *Proteacidites Symphyonemoides*. (Cookson, 1950, p. 172, pl. 2, fig. 17). This type can be referred to *Reticulo-triorites* of Erdtman (1947, p. 110).

Type No. 17. Grain partly broken, flat, oblique polar view, (Pl. XVII, fig. 7; Pl. XVIII, fig. 7) 27·3μ × 27·3μ, triangular, with slightly convex sides, pores three, one at each angle, aspidate, 2·5μ deep, 3·3μ in diameter. Exine 1·1μ thick, smooth, subexineous thickening (2μ); light yellow. This type can be referred to *Psilo-triorites* of Erdtman (1947, p. 110).

Type No. 18. Grain flat, discoid. Polar view hexagonal (Pl. XVII, fig. 8; Pl. XVIII, fig. 8) 41·6μ × 43·2μ, pores three (p), depressed, very broad, and 23·4μ long, and forming the three alternating sides of the hexagon. Exine 5μ thick, piliferous; brown. This type can be referred to *Pilo-triorites* of Erdtman (1947). It is quite likely that the above referred pores are really transverse furrows disposed along the equatorial region of the grain. The grain would then come under the *Tricolpate* type.

Tricolpate. *Tricolpites* of Erdtman (1947).

Type No. 19. The two figures and the photograph (Pl. XVII, fig. 9–10; Pl. XVIII, fig. 9) are of the polar views at different foci. Polar view triangular (Pl. XVII, fig. 9; Pl. XVIII, fig. 9), 32·0μ × 28·8μ, sides convex. Colpae deep broad in the middle equatorial region, and narrowing towards the poles and almost meeting in the centre of the polar area (Pl. XVII, fig. 10). Ektexine smooth, hyaline and 2·5μ thick; intexine 1μ thin. Surface granular; light yellow. This type resembles the pollen of *Quercus sp.* (Wilson and Webster, p. 183, pl. 2, figs. 33–35), and more closely *Quercus agrifolia* (Wodehouse, 1935, p. 379) in shape and size.

Type No. 20. (Pl. XVII, figs. 11–12; Pl. XVIII, figs. 10–11). Pl. XVII, fig. 11; Pl. XVIII, fig. 10 show the polar view which is round, trilobed, 28·8μ × 28·8μ; the oblique polar view (Pl. XVII, fig. 12; Pl. XVIII, fig. 11) shows one of the furrows clearly. The grain is cleft by the furrow which is deep and broad in the equatorial part and narrow in the polar area. Ektexine narrow, about 1μ thick, smooth or slightly granular. Intexine about 1·3μ thick; light yellow. This grain is very much like *Type 19*, except that the exine is comparatively thinner and slightly granular. It offers a comparison with *Quercus robur* (Erdtman 1943, p. 100, figs. 192-193). A resemblance in appearance but not in size can be made out between this type and *Tricolpites* Spm. described by Mrs. Chitaley (1951, Pl. 13, fig. 13b and text fig. 15) from the Eocene beds of Mohgaon Kalan.

Type No. 21. Grain flat. Polar view (Pl. XVII, fig. 13; Pl. XVIII, fig. 12), triangular, sides convex, 35·7μ × 35·7μ furrow broad towards the middle and narrowing towards the ends, mostly confined to the equatorial part of the grain. Ektexine 1·9μ thick, granular, intexine 2·0μ thick; light yellow. It may be that the structures regarded as furrows in this grain are really elongated pores; then a very close comparison can be made between this grain and the grain of *Betula tortusa*, *B. lenta* and *Carpinus betulus* (Erdtman, 1943, pp. 74, 76, figs. 72–73, 67–68, 76–78). But in size it resembles the last species, the other two being smaller.

Type No. 22. Grain thin, flat and tricolpate. Polar view (Pl. XVII, fig. 14; Pl. XVIII, fig. 13) round, 53·5μ × 53·5μ, three lobed, lobes deep, broad at the periphery and narrowing towards the centre. Colpae broad and deep. Exine 2·5μ thick, surface positively reticulate; yellow. This grain resembles *Type 7* (Rao and Vimal, 1950), but differs from it in being bigger and having a different surface sculpture.

Type No. 23. (Pl. XVII, figs. 15–16; Pl. XVIII, fig. 14) grain spherical, probably tricolpate. Pl. XVII, figs. 15–16 are oblique polar views at lower and higher foci respectively, 29·6μ × 30·7μ. The grain has split into three flanges (probably due to pressure) and perhaps along the three colpae. The outer sides of the flanges are convex, the colpae are deep and broad. Exine 3·3μ thick, finely granular; light yellow. This type can be compared with the pollen of *Acer negundo* in size, shape and surface sculpture. (Wodehouse, 1935, p. 441;

Erdtman, 1943, p. 66, figs. 36–37). This type can be referred to *Ob-tricolpites* of Erdtman (1947, p. 109).

Type No. 24. (Pl. XVII, figs. 17–20; Pl. XVIII, figs. 15–16). Pl. XVII, figs. 17–18 show the equatorial views of the grain at different foci. Pl. XVII, figs. 19–20 show similarly the polar views at higher and lower foci. Pl. XVII, fig. 17 and Pl. XVIII, fig. 15 show the equatorial view with the two flanges in focus and here the grain appears almost round and measures 34·6μ from pole to pole and 32·4μ along the equatorial diameter. The thin slit like furrow separating the two flanges can be seen in the middle. Pl. XVII, fig. 18 is another oblique equatorial view with only one flange in focus. The two hazy areas on the two sides are the remaining two flanges. Polar view (Pl. XVII, figs. 19–20; Pl. XVIII, fig. 16), circular, three lobed, lobes (flanges) separated from each other by wedge-shaped colpae which however do not meet, polar dimensions of the grain 35·7μ × 36·9μ. Each flange is convex on the outer side and 23·8μ broad at the periphery. Exine granular, granules thick and close, forming a negative reticulum; light yellow. This grain can also be included under the *Brachytrilistriate* type of Naumova (1937, p. 355). This type can perhaps come under the *Ob-tricolpites* of Erdtman (1947, p. 109).

Pollen like types 22–24 are reported from the Tertiary lignites of South Arcot, Madras (Jacob and Jacob, 1950) but they are Tricolporate, while ours are tricolpate and do not show any pores at all.

Type No. 25. (Pl. XVII, figs. 21–22; Pl. XVIII, fig. 17). Almost round, tricolpate, (? Brachitrilistriate), Pl. XVII, fig. 21; Pl. XVIII, fig. 17 are equatorial views showing the two flanges and the narrowing slit-like colpa, (48·0μ × 38·4μ). Pl. XVII, fig. 22 is the same grain seen at a different focus showing the third flange. A part of another flange is seen on the right. The flanges measure 22·1μ broad in the equatorial view (Pl. XVII, fig. 21; Pl. XVIII, fig. 17). Exine 2·4μ thick with long prismatic thickenings which present a characteristic granular appearance in surface view. There is a subexineous thickening (? intexine) 2·2μ thick; light brown.

Type No. 26. (Pl. XVII, figs. 23–25; Pl. XVIII, figs. 18–19). Grain spherical but slightly ruptured, tricolpate. (Pl. XVII, fig. 23; Pl. XVIII, fig. 18) show the equatorial view of the grain where the two flanges are in focus. Pl. XVII, fig. 24; Pl. XVIII, fig. 19 show another equatorial view of the same grain at a different focus showing the third flange. Dimensions of the grain as seen in the equatorial view (Pl. XVII, fig. 23; Pl. XVIII, fig. 18) are 83·3μ × 82·0μ. The flanges as seen in Pl. XVII, fig. 24; Pl. XVIII, fig. 19 appear to be widely separated at one pole and more or less united at the other pole. But Pl. XVII, fig. 23; Pl. XVIII, fig. 18 show the two flanges slightly separated from each other. This might be just a tear in the grain. In fact the appearance of the grain is rather unusual and does not seem to represent its natural form. The two flanges are slightly flattened, broad at one end and narrowed towards the other, where they seem to be united and forming one of the poles of the grain. The broad translucent layer (*e* in Pl. XVII, fig. 25) may be the exine which is 5·9μ thick and piliferous. The prominent papillae seen on the surface of the grain (shown only in fig. 24 but not in 23) have a round or slightly angular head and a narrow stalk which seem to go as far down as the inner limit of the exine referred to above (see Pl. XVII, fig. 25). The papillae measure on the average 3·5μ long and 2·3μ broad. The stalk is 7·1μ long and 1·1μ thick; light brown.

Type No. 27. (Pl. XVII, figs. 26–28; Pl. XVIII, fig. 20). Tricolpate, and rather small in size. Pl. XVII, fig. 26 shows the broadly elliptic equatorial view (21·4μ × 23·4μ), with the two flanges and the slit like colpa in focus. Pl. XVII, fig. 27 shows again an equatorial view with the third flange in focus. Pl. XVII, fig. 28; Pl. XVIII, fig. 20 show the polar view of the same grain (26·1μ × 27·3μ). Exine very minutely granular; light yellow. This type can perhaps come under the *Ob-tricolpites* of Erdtman (1947).

Type No. 28. (Pl. XVII, figs. 29–30; Pl. XVIII, figs. 21-22). Tricolpate, Pl. XVII, fig. 29; Pl. XVIII, fig. 21 show the equatorial view of the grain (85·6μ × 78·4μ) with the two flanges in focus and the outline of the third flange seen hazily. The thin slit (seen better in Pl. XVII, fig. 29) in the middle, is the colpa separating the two flanges. Pl. XVII, fig. 30; Pl. XVIII, fig. 22 show the same grain at a different focus with the third flange in view. The flanges are 48·8μ broad and 78·4μ long, more or less oval in surface view and are convex on the outer side. Exine 4·0μ thick and positively reticulate; brown. This grain in similar to Type 24 in general form and may also be included under the Brachitrilistriate type.

Tetracolpate. Tetracolpites of Erdtman (1947).

Type No. 29. (Pl. XVII, figs. 31–33; Pl. XVIII, fig. 23). Thin and flat. Pl. XVII, fig. 31; Pl. XVIII, fig. 23 show the polar view of the grain (22·4μ × 24·0μ) with its cruciform shape and the four colpae placed at diagonally opposite sides, and measuring 3·5μ broad and 4·0μ deep. The grain being very thin does not rest on its narrow equatorial face. So it was not possible to take a photograph or make a very accurate sketch. But still Pl. XVII ,figs. 32–33 are semidiagrammatic sketches of the equatorial view of an entirely different grain of the same species. Pl. XVII, fig. 32 shows the perfect equatorial view with the central

flange in the middle. Pl. XVII, fig. 33 is an oblique equatorial view of the same grain showing three flanges only on one side. Exine 3·5μ thick, surface sculpture granular; light yellow. This type can come under the *Per-ob-tetracolpites* of Erdtman (1947).

Pentacolpate. *Pentacolpites* of Erdtman (1947).

Type No. 30. Grain, thin, flat and with five narrow colpae. Polar view round (Pl. XVII, fig. 34; Pl. XVIII, fig. 24), 28·5μ in diameter. Colpae five, narrow and 3·5μ deep. Exine 3·5μ thick, translucent and granular; light yellow. This type can come under the *Per-ob-pentacolpites* of Erdtman (1947).

Hexacolpate. *Hexacolpites* of Erdtman (1947).

Type No. 31. (Pl. XVII, figs. 35–36; Pl. XVIII, fig. 25). Grain discoid, sixcolpate. Polar view (Pl. XVII, fig. 35; Pl. XVIII, fig. 25) round, 35·7μ in diameter, six lobed, lobes 17·9μ broad and almost flat at the periphery and separated by deep (11·9μ) colpae. The two lobes have been slightly pressed out of position. Pl. XVII, fig. 36 is a very diagrammatic equatorial view of the grain showing only three lobes and the two intervening furrows in focus. Equatorial dimensions could not be made out as the grain does not rest on this surface. Exine 4·7μ thick and granular; brown. This type can come under the *Ob-hexacolpites* of Erdtman (1947).

Summary.

Twenty different types of pollen are described in detail from some lignites from Palana in Bikaner District in Rajasthan. Some of these pollen are comparable to the following genera of living plants: *Betulaceae*; *Betula lenta*, *B. tortusa*; *Fagaceae*; *Quercus robur*, *Q. agrifolia*; *Aceraceae*; *Acer negundo*; *Proteaceae*; *Proteacidites symphyonemoides*.

The lignites referred to above probably belong to a fresh-water deposit as is evidenced by the occurrence of a large number of *Botryococcus Braunii*—a fresh-water alga, and the pollen of the *Potamogeton* type. Pollen of terrestrial plants seen in the matrix were probably blown by the wind into the fresh water. Some of the pollen grains described in this paper resemble those found in the Eocene beds of Green River (Colarado, Utah., U.S.A.) and also in the Tertiary deposits of Australia.

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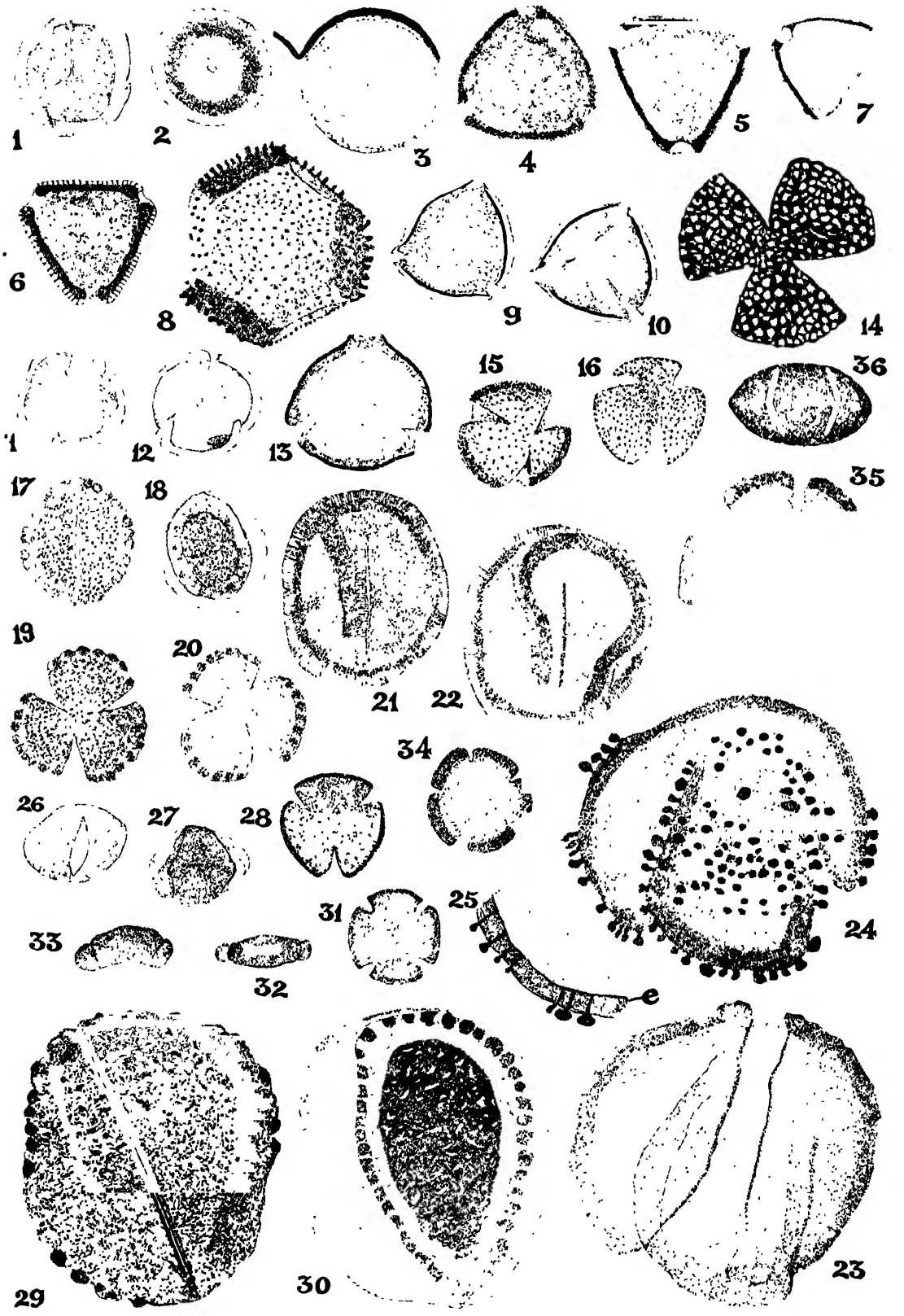
Plate XVII.

Explanation of Figures.

Figs. 1–36. *Aporosa*, 1; *Monoporosa*, 2 & 3; *Triporosa*, 4–8; *Tricolpate*, 9–30; *Tetracolpate*, 31–33; *Pentacolpate*, 34; *Hexacolpate*, 35-36.

Explanation in text. All figures magnified 650 times.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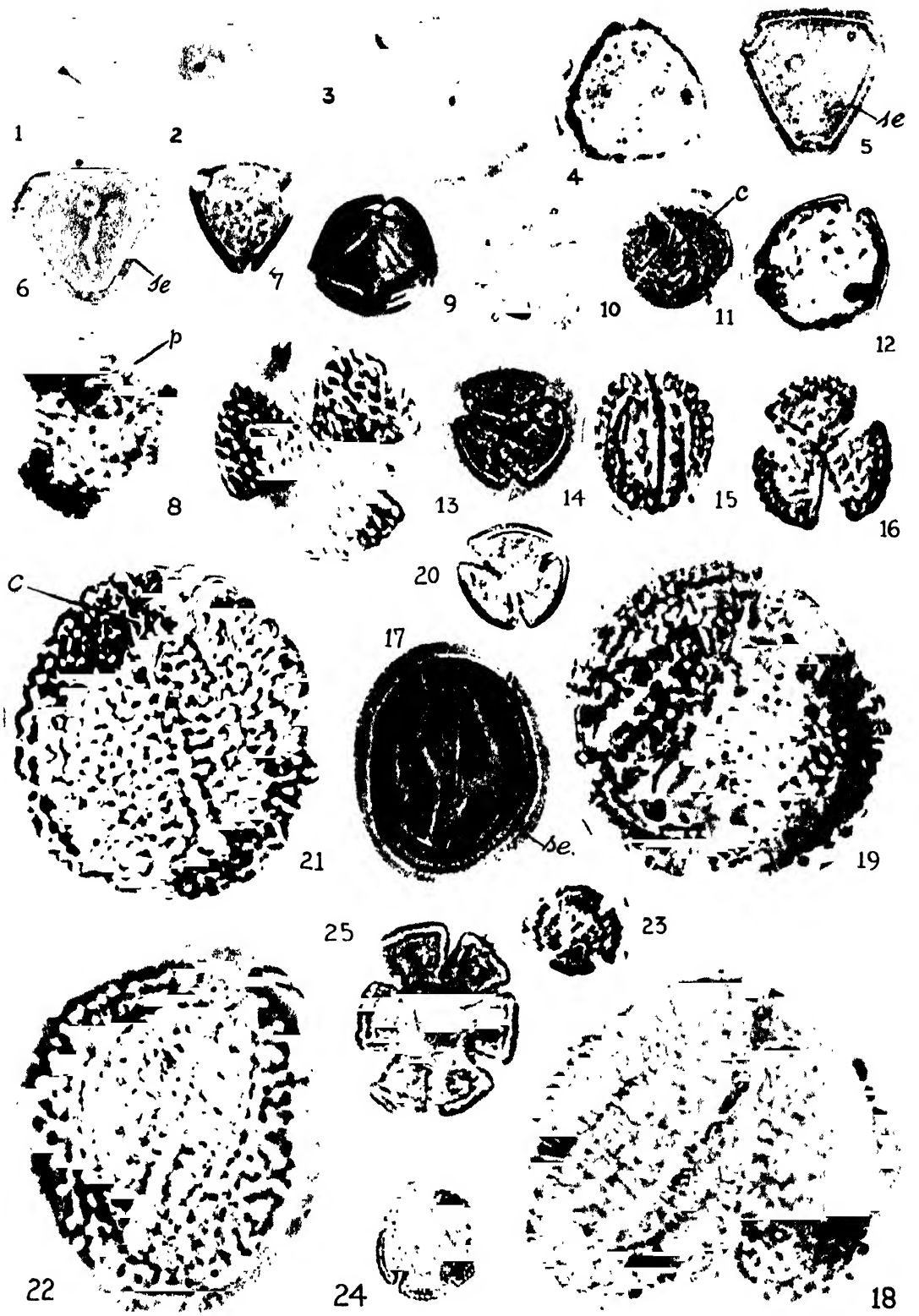
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PLATE XVIII.

EXPLANATION OF PHOTOGRAPHS.

All photographs show the grains magnified 566 times.

Aporosa: Photo **1**, Type 11, (25·0μ × 22·4μ), polar view showing triradiate mark.

Monoporosa: Photo **2**, Type 12, (28·8μ × 28·8μ), polar view showing single pore. **3**, T.13, (35·5μ × 35·5μ), polar view showing the solitary pore and peeled off exine.

Triporosa: Photo **4**, Type 14, (33·6μ × 35·2μ), polar view showing one pore at each angle. **5**, T.15, (36·8μ × 36·8μ), polar view, a pore at each angle, subexineous thickening (*s.e.*) seen. **6**, T.16, (34·5μ × 34·5μ), polar view, subexineous thickening (*s.e.*) very clear. **7**, T.17, (27·3μ × 27·3μ), polar view showing aspidate pores, portion near one of the pores partly broken. **8**, T.18, (41·6μ × 43·2μ), polar view, showing broad pores (*p*) and papillate exine.

Tricolpate: Photo **9**, Type 19, (32·0μ × 28·8μ), polar view showing the three colpae. **10**, T.20, (28·8μ × 28·8μ), polar view showing the three colpae. **11**, oblique polar view of the same grain showing one of the elongated colpae (*c*). **12**, T.21, (35·7μ × 35·7μ), polar view showing the three colpae. **13**, T.22, (53·5μ × 53·5μ), polar view showing the three wedge-shaped lobes, deep colpae and reticulate exine. **14**, T.23, (29·6μ × 30·7μ), slightly oblique polar view showing the two colpae clearly in the upper part of the photograph. **15**, T.24, (34·6μ × 32·4μ), equatorial view showing two flanges, the colpa between them and the granular exine. **16**, polar view (35·7μ × 36·9μ), of the same grain showing the broad lobes and the colpae. **17**, T.25, (48·0μ × 38·4μ), equatorial view showing the thin colpa separating the two flanges, the third colpa behind is not in focus; the dark band (*s.e.*) appears to be a subexineous thickening. **18**, T.26, (83·3μ × 82·0μ), equatorial view at a lower focus showing the two flanges, the one on the right side has been pressed out of position. The flange on the extreme left which is partly seen in photo 18 is seen clearly in photo 19, which is another view of the same grain at a slightly different focus. **20**, T.27, (21·4μ × 23·4μ), polar view showing the broad flanges, deep colpae and the minutely granular exine. **21**, T.28, (85·6μ × 78·4μ), equatorial view showing the two flanges, and the intervening colpa (*c*) and the reticulate surface sculpture. **22**, another equatorial view of the same grain at a higher focus showing only one flange. The hazy areas on the two sides of this are the other two flanges, the colpa on the other side can also be seen.

Tetracolpate: Photo **23**, Type 29, (22·4μ × 24·0μ), polar view, the small dark round marks seen in the photograph do not belong to the grain but belong to the mounting medium.

Pentacolpate: Photo **24**, Type 30, (28·5μ × 28·5μ), polar view showing the five lobes and the reticulate exine.

Hexacolpate: Photo **25**, Type 31, (35·7μ × 35·7μ), polar view of the discoid grain showing the six lobes with flat outer surfaces.

NUTRIENT EFFECT UPON CHLOROPHYLL CONTENT OF SUGARCANE LEAVES.

By K. N. Lal, M. S. Subba Rao *and* Rajat De, *Plant Physiological Laboratory College of Agriculture, Banaras Hindu University, Banaras.*

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Introduction.

Chlorophyll plays an important rôle in the development of the assimilating system of plants (Schertz, 1921). Its concentration varies with age and maturity (Deleano *and* Dick, 1935; Mackinney, 1935; Murneek, 1934; Ram *and* Chetty, 1934; Wood, 1941; Wood, Cruickshank *and* Kuchel, 1943; Zaitzeva, 1940), day length (Beck, Redman *and* Schroeder, 1937; Chailakhian, 1934; van Hille, 1938), quality and intensity of illumination (Alexandrov, 1929; Beck, Redman *and* Schroeder, 1937; Beck, 1938; Biebel, 1942; Goodwin *and* Owens, 1947; Hicks *and* Panisset, 1934; Strain, 1934; Strott, 1938), season (Beck *and* Redman, 1940), and environment (Gutherie, 1929; Ulvin, 1934; Whiteside, Edger *and* Goulden, 1934). Pigment ratios also vary in sun and shade leaves (Ram *and* Chetty, 1934) in response to nutrients and soil conditions Ijdo, 1935; Singh, 1941; Strott, 1938) in general, and nitrogen (Tam *and* Magistead, 1935), iron (Hill *and* a Lehmann, 1941; Jacobson, 1945; Sideris *and* Young, 1944), chlorides (Basslavskaya *and* Syroeshkina, 1936; Inman, Barclay *and* Hubbard, 1935), magnesium (Rissman, 1939; Strain, 1934) and potassium (Gassner *and* Goeze, 1934; Sideris *and* Young, 1945) in particular. Relation between chlorophyll and proteins (Hanson, Barrien *and* Wood, 1941; Noack, 1927; Sideris, 1947), photosynthesis (Arnold *and* Kohn, 1934; Emerson *and* Webb, 1940; Fleischer, 1935; Stoll, 1936; van Hille, 1938), respiration (Noack, 1927) catalase, peroxide and aldehyde content (Euler, Hertzsch, Forssberg *and* Hellstrom, 1931) in plants is also visualised. In chlorotic pine apple plants, iron with ammonium or nitrate ions induces variations in ascorbic and other organic acids depending largely on the rate of nitrate reduction (Sideris, 1944). Chlorophyll is suggested to be adsorbed on plastids (Stoll, 1936) imparting properties related to its biological functions (Hanson, 1939). A comprehensive account of factors affecting chlorophyll content along with the biochemistry of this plant pigment appears elsewhere (Aronoff, 1950).

This paper reports the results of experiments on sugarcane under varying conditions of nutrition. Variations in chlorophyll content of leaves have been analysed in terms of the levels and ratios of nitrogen, phosphorus and potassium, age of plants and development stages of leaves. The investigations were initiated in 1937 by Singh *et al.* and continued subsequently by Lal and co-workers. The evidences collected in different directions are marshalled together to provide a complete picture of the responses of nutrients on chlorophyll content of sugarcane plant.

Experimental Procedure.

Sugarcane plants were grown in pots of different sizes, 10″×12″, 12″×18″ and 18″×24″, each filled with a known quantity of soil or sand. All calculations of the nutrients added were indicated in p.p.m. of the weight of sand or soil used, or in lbs.

per acre calculated on the basis of top surface area of pots. Adequate attention was given to irrigation, weeding and hoeing so as to provide normal conditions for sugarcane growth. Nutrients were added in the form of inorganic fertilisers, organic bulky manures, or pure salts in the different experiments which have been described in detail in earlier publications (Singh, 1937–42, 1941a, 1941b). Only the summarised results pertaining to leaf pigments are presented in this paper. For details of the quantity of sand or soil, amount of nutrients or number of cultures, reference may be made to the original sources from where these observations were collected.

Chlorophyll content or concentration of various pigments was estimated on fully expanded leaves on the main shoot, sampled at certain specified stages of life cycle, and kept overnight in the laboratory with their cut ends dipped in water. Portions of lamina excluding midrib were removed and chopped into fine pieces. 1 to 5 gms. of the fresh material prepared in this way was extracted with 25 to 50 c.c. of 3 : 7 ether-acetone mixture. Extraction was completed in a dark chamber at the prevailing room temperature or in an electric incubator at 35°C. Wherever extraction was not complete within seventy-two hours, further extraction was continued in a Soxhlet. Maceration of tissues with fine quartz sand and subsequent extraction of pigments in an electric incubator at 35°C. was also found helpful.

Ether-acetone extract was made up to a known volume and the content of total chlorophyll was estimated by Oltman's apparatus (Oltman, 1933) and expressed in milligrams per ten grams of fresh material unless otherwise stated. For estimation of different pigments, viz., chlorophyll *a*, chlorophyll *b*, carotin and xanthophyll, the ether-acetone extract was separated into these pigments according to the procedure indicated elsewhere (Loomis *and* Shull, 1937; Schertz, 1928). Pigment concentration was determined by Klett Colorimeter using Guthrie's standards (Guthrie, 1928) for the green and yellow pigments. For all comparative studies as the one reported in these pages, this method of estimation was found to be quite helpful.

Experimental Results.

(*a*) *Effect of nitrogen, potassium and phosphorus on chlorophyll content of sugarcane leaves.*

Chlorophyll content of leaves under conditions of pot culture varied with the fertiliser and the ratio in which the three ingredients were applied. As a rule, nitrogen applied at 150 lbs. level either singly or in combination with potassium or phosphorus induced higher chlorophyll content than cultures not supplied with nitrogen. Average response of nitrogen was significant in the year 1937–38 but not so in a subsequent season (Table 1). Phosphorus and potassium at 75 lbs. P_2O_5 and 75 lbs. K_2O failed to evince any significant response in these soils, when varying N, P, and K levels were maintained in the sand cultures.

100 lbs. of N significantly improved chlorophyll content above the values recorded for the control. Application of phosphorus at 37·5 lbs. or 75 lbs. P_2O_5 significantly reduced chlorophyll content below the value recorded for the control. Potassium at the lower levels of 25 lbs. K_2O also proved deleterious. Heavier doses of 50 lbs. K_2O on the contrary, significantly improved chlorophyll over that recorded for 25 lbs. K_2O cultures (Table 2).

Subsequent investigations on the effect of varying levels and combinations of N, P and K in sand nutrient cultures showed that chlorophyll content reached the highest level when nitrogen was added at 20 p.p.m. of sand. Further increases of N beyond this appeared deleterious (Table 3, Fig. 1). Increases in phosphorus also raised chlorophyll content to the highest level under 20 p.p.m. of P_2O_5. Further additions showed a negative effect. In the potassium cultures

TABLE 1.

Chlorophyll content in mgm. per 10 gm. fresh weight of sugarcane in soil cultures. *

Age in days.	C	N	P	K	NK	NP	PK	NPK
			1937–38					
	18·0	21·9	22·5	22·5	25·1	23·5	21·7	21·7
			1938–39					
45 ..	4·4	8·2	7·5	6·5	6·9	5·1	6·4	8·5
135 ..	5·1	9·3	7·4	6·4	6·2	6·1	6·4	9·0
225 ..	6·1	10·1	7·5	6·3	7·8	7·1	5·8	10·5
Mean ..	5·2	9·2	7·4	6·4	6·9	6·1	6·2	9·3

Mean responses

	N	P	K
1937–38 ..	1·62 ± 0·80*	1·27 ± 1·32	0·47 ± 1·46
1938–39 ..	1·58 ± 0·97	0·76 ± 1·06	−0·19 ± 1·06

* From Singh (1941a).

TABLE 2.

Chlorophyll content of leaves in mgm. per 10 gms. fresh weight under different treatments in sand cultures.†

	K_0			K_1			K_2		
	P_0	P_1	P_2	P_0	P_1	P_2	P_0	P_1	P_2
N_0 ..	24·8	21·2	21·2	12·4	14·8	9·2	25·2	11·6	16·0
	25·0	*22·0*	*23·0*	*15·0*	*15·5*	*10·8*	*27·1*	*14·5*	*20·0*
N_1 ..	16·8	12·4	19·6	39·6	13·6	14·8	16·8	32·4	16·8
	18·0	*15·0*	*20·0*	*42·0*	*16·0*	*17·0*	*20·0*	*36·4*	*20·0*
N_2 ..	29·6	44·0	19·6	21·2	10·4	16·8	49·6	12·4	12·4
	32·0	*48·0*	*21·0*	*24·0*	*12·8*	*19·0*	*55·0*	*15·8*	*16·0*

Upper figures for 45 days, lower (italics) for 120 days.

Mean responses.

	45 days	120 days
N_1–N_0 ..	2·93 ± 2·76	3·50 ± 3·40
N_2–N_0 ..	6·63 ± 1·64**	8·69 ± 0·84**
N_2–N_1 ..	3·68 ± 3·77	2·44 ± 3·24
P_1–P_0 ..	−7·02 ± 2·50*	−7·00 ± 3·20*
P_2–P_0 ..	−9·96 ± 2·12**	−10·15 ± 2·10**
P_2–P_1 ..	−2·93 ± 1·31*	0·18 ± 2·11
K_1–K_0 ..	−6·27 ± 2·41*	−3·25 ± 1·55*
K_2–K_0 ..	−1·78 ± 2·67	0·10 ± 2·80
K_2–K_1 ..	4·45 ± 0·92**	5·80 ± 2·90*

† From Singh *et al.* (1937–42).

none of the treated series shew higher chlorophyll content than the control. On the contrary, additional potassium proved deleterious. In another series of experiments where varying N, P, and K levels were applied to the cane, it was noted that under sand nutrient culture conditions, nitrogen at N_1 (75 lbs. N) or N_2 (150 lbs. N) was helpful in improving chlorophyll content over that of the control. Other treatment effects were not significant (Table 4).

TABLE 3.

Chlorophyll content per unit weight of leaves under increasing doses of N, P, and K with basal dressings of other two in pot cultures in sand medium. *

Levels of N p.p.m.	Chlorophyll in mgm.	Levels of P p.p.m.	Chlorophyll in mgm.	Levels of K p.p.m.	Chlorophyll in mgm.
0	6·85	0	9·35	0	11·25
10	6·85	5	10·60	5	8·75
20	11·25	10	8·10	10	..
30	8·75	15	..	15	7·50
40	..	20	11·25	20	6·25
50	8·75	25	10·00	25	7·00
60	..	30	9·00	30	9·35

* Basal nutrition in N series = 20 p.p.m. each of P_2O_5 and K_2O ; P series—N at 30 p.p.m and K_2O at 20 p.p.m.; K series—N at 30 p.p.m. and P_2O_5 at 20 p.p.m.

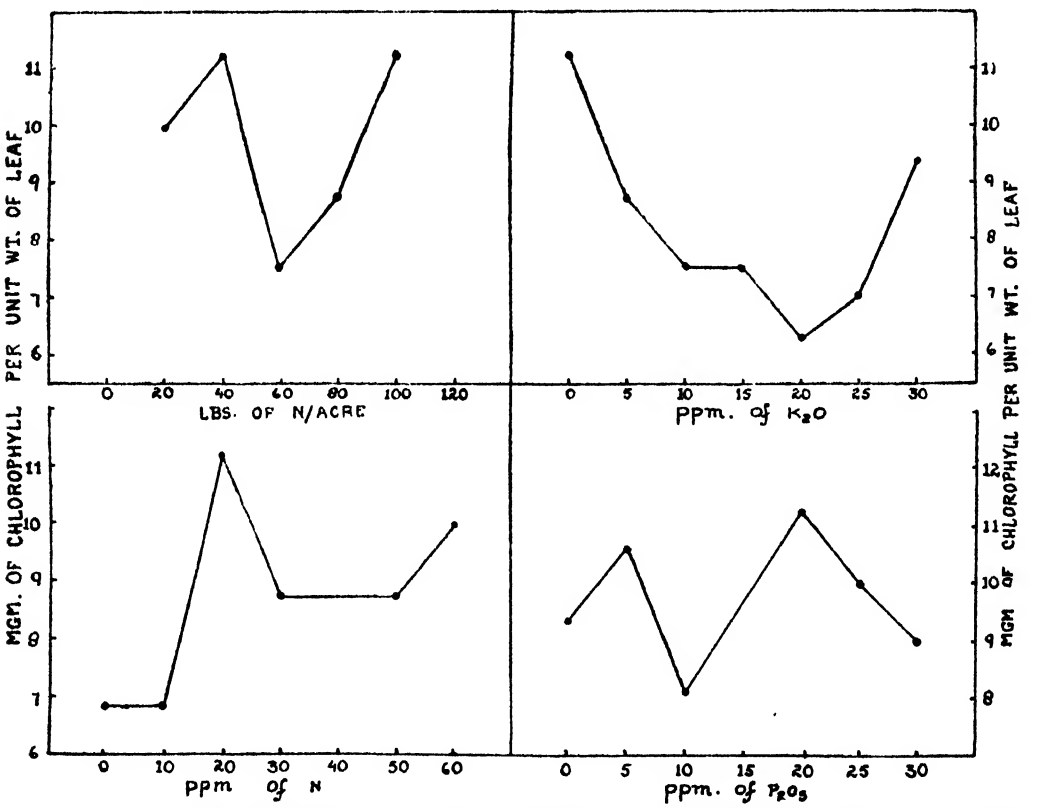

FIG. 1. Effect of various levels of N, P_2O_5 and K_2O upon chlorophyll content of sugarcane leaves.

TABLE 4.

Chlorophyll content of mature leaves under different conditions of treatments in sand cultures.

	K_0			K_1			K_2		
	P_0	P_1	P_2	P_0	P_1	P_2	P_0	P_1	P_2
N_0 ..	1·0	3·7	2·6	1·2	2·8	2·4	1·2	1·9	3·7
N_1 ..	5·9	6·2	5·6	5·2	6·2	5·0	5·0	2·5	3·1
N_2 ..	6·0	6·2	3·7	3·2	5·8	5·0	5·4	6·9	3·1

Mean responses.

N_1-N_0 ..	2·72 ± 0·55**	P_1-P_0 ..	0·94 ± 0·5	K_1-K_0 ..	−0·66 ± 0·35
N_2-N_0 ..	2·66 ± 0·54**	P_2-P_0 ..	0·55 ± 0·6	K_2-K_0 ..	−1·01 ± 0·79
N_2-N_1 ..	0·07 ± 0·58	P_2-P_1 ..	0·55 ± 0·6	K_2-K_1 ..	−0·36 ± 0·58

(*b*) *Effect of inorganic and organic manures.*

Investigations conducted in this direction shew the most helpful effect of fish guano among the organics and of sodium nitrate among the inorganics during the early stage of 30 days. During a later period of 210 days, bone dust appeared better than other organics while nitrate of potash proved more helpful than other inorganics. At both these stages the average chlorophyll content in the inorganic group was higher than that recorded for the organic group (Table 5, Fig. 2).

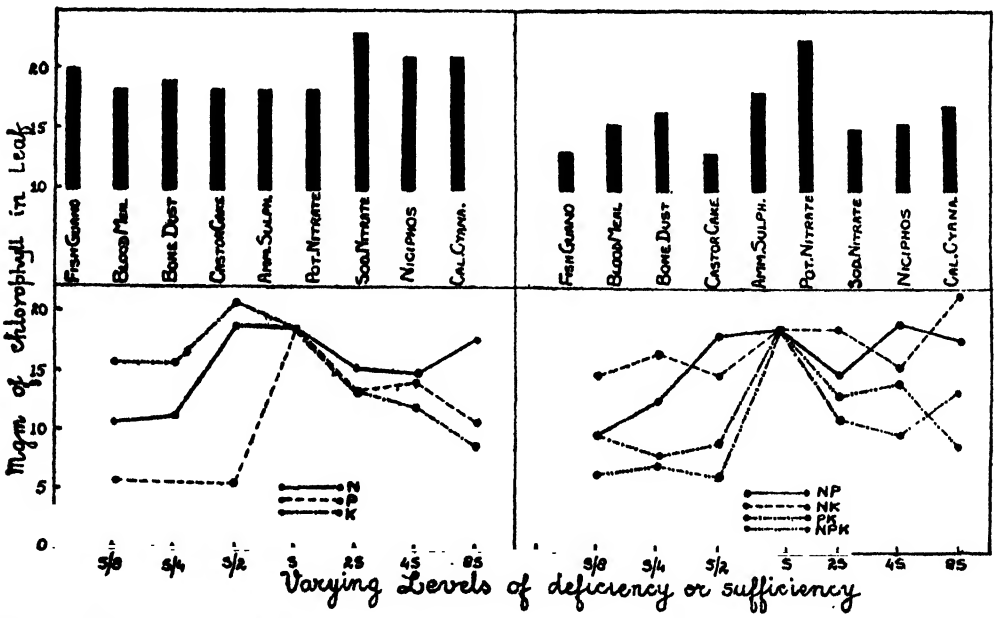

FIG. 2. Effect of various forms of manure and varying levels of deficiency and sufficiency upon chlorophyll content of sugarcane leaves. (upper left 30 days; upper right 210 days).

TABLE 5.

Chlorophyll content in mgm. per 10 gms. fresh weight of leaves under different organic and inorganic fertilisers in soil cultures in pots. *

Treatments	30 days	210 days
Fish guano	20·0	13·0
Blood meal	18·2	15·5
Bone dust	19·0	16·5
Castor cake	18·2	13·0
Sulphate of Ammonia	18·2	18·0
Nitrate of potash	18·2	22·5
Nitrate of Soda	23·0	15·0
Niciphos	21·0	15·5
Calcium Cynamide	21·0	17·0

* From Singh (1937–42).

TABLE 6.

Chlorophyll content of leaves in mgm. per 10 gms. fresh weight under half and half mixtures of organic and inorganic manures in soil. *

Treatments	Fish guano	Blood meal	Bone dust	Caster cake
Sulphate of Ammonia	21·0	18·2	17·5	20·5
	17·5	*18·0*	*21·5*	*15·5*
Nitrate of potash	20·5	20·0	20·0	21·0
	12·5	*12·0*	*19·0*	*15·5*
Nitrate of Soda	15·5	17·0	18·2	19·0
	14·5	*18·0*	*17·0*	*12·5*
Niciphos	19·0	37·5	15·5	34·0
	21·5	*19·5*	*15·0*	*15·5*
Calcium cyanamide	19·0	16·0	24·5	20·5
	14·5	*12·5*	*15·0*	*13·5*

Upper figures for 30 days and lower (italics) for 210 days. * From Singh (1937–42).

TABLE 7.

Chlorophyll content in mgm. per 10 gms. fresh weight of leaves under various conditions of deficiency and sufficiency of fertilisers. *

Levels	N	P	K	NP	NK	PK	NPK
S/8 ..	10·6	5·9	15·5	9·6	14·7	9·6	6·5
S/4 ..	11·0	5·6	15·5	12·5	16·5	8·0	7·4
S/2 ..	18·9	5·7	20·5	18·0	14·8	9·1	6·4
S ..	..	..	..	..	..	..	18·6
2 S ..	15·2	13·2	13·2	14·8	18·7	11·2	13·0
4 S ..	14·9	14·0	12·0	19·0	15·5	9·9	14·3
8 S ..	17·7	10·8	8·7	17·6	21·2	13·4	8·6

* From Singh (1937–42).

Further, in half and half mixtures of organic and inorganic manures, chlorophyll content of sugarcane leaves at 30 days was highest in a mixture of niciphos and blood meal. At 210 days, half and half mixture of niciphos and fish guano shew the highest chlorophyll content each applied at 75 lbs. N. level. A mixture of sulphate of ammonia and bone dust at similar levels was equally effective (Table 6).

(c) *Effect of mineral deficiency and excesses on chlorophyll content of sugarcane leaves*:

Application of N, P, or K in varying quantities below and above the standard fertiliser mixture of 150 lbs. N and 75 lbs. each of P_2O_5 and K_2O (Singh, 194b) shew the outstanding effect of nitrogen and phosphorus. Deficiency of nitrogen lowered the chlorophyll content consistently with each increase in the level of deficiency. Phosphorus deficiency reduced chlorophyll content at all the levels below that of the standard phosphorus culture. Slackened supply of potassium was least effective in lowering chlorophyll content (Table 7, Fig. 1). Increases in the level of all the three ingredients N, P and K singly at a time, lowered chlorophyll content below that of the standard treatment. In general, the higher the dose of these ingredients the lower was the chlorophyll content. When two or three elements were maintained deficient or in excess, the results were equally interesting in as much as the deficiencies of NP, NK, PK, NPK all reduced chlorophyll content below that of the standard culture (S). On the sufficiency side added doses of NP, and NK appeared more helpful than increases in PK or NPK at 2, 4, or 8 times the normal level maintained in the standard culture (Table 7).

(d) *Effect of nitrogen, potassium and phosphorus on the chlorophyll content under field conditions*:

In field, nitrogen at 40 lbs. level proved to be most helpful in improving chlorophyll content of leaves. Higher levels of 60 and 80 lbs. N were found to be inferior in chlorophyll formation (Table 8). When varying N, P, and K

TABLE 8.

Chlorophyll content of mature leaves of sugarcane under increasing doses of nitrogen under field conditions.

Dose of N	Chlorophyll content
20 lbs.	10·0
40 lbs.	11·2
60 lbs.	7·5
80 lbs.	8·7
100 lbs.	11·2

combinations were applied in a factorial experiment under field conditions, variations in chlorophyll content were found amongst the differently treated plots. Analysis of the response of these fertilisers showed the most significant effect of 75 and 150 lbs. nitrogen level in improving the chlorophyll content of leaves. Increase in phosphorus from 37·5 lbs. to 75 lbs. P_2O_5 also proved helpful in raising the chlorophyll content. Other treatments were insignificant in effect (Table 9).

TABLE 9.

Chlorophyll content of mature leaves under different treatments under field conditions.

	K_0			K_1			K_2		
	P_0	P_1	P_2	P_0	P_1	P_2	P_0	P_1	P_2
N_0 ..	4·6	5·0	7·5	6·0	6·2	6·4	8·1	3·1	8·7
N_1 ..	10·0	8·7	8·7	8·7	5·0	9·3	7·5	6·8	9·2
N_2 ..	9·6	8·7	9·4	8·1	10·0	8·75	9·4	9·3	10·2

Mean responses

N_1–N_0 ..	2·04 ± 0·68**	P_1–P_0 ..	1·09 ± 0·65	K_1–K_0 ..	−0·44 ± 0·53
N_2–N_0 ..	3·09 ± 0·53**	P_2–P_0 ..	0·68 ± 0·36	K_2–K_0 ..	0·01 ± 0·60
N_2–N_1 ..	1·06 ± 0·57	P_2–P_1 ..	1·70 ± 0·69*	K_2–K_1 ..	0·42 ± 0·57

(*e*) *Pigment content of sugarcane varieties*:

Of the eight varieties of sugarcane, maximum chlorophyll *a* content was noticed in Co 453 and minimum in ORB 79. Chlorophyll *b* content was, however, maximum in Co 448 and minimum in Co 356. In general, Co 453, 448 and 421 showed relatively higher content of chlorophyll as compared to other varieties. Carotin content on the other hand, was highest in ORB 191, while xanthophyll was highest in Co 453. Total yellow pigments were highest in Co 453 followed by ORB 191 and Co 448. Other varieties showed relatively lower content of yellow pigments (Table 10).

TABLE 10.

Pigment content of different varieties of sugarcane in mgm. per 10 gms. fresh weight.

Variety	Chloro-phyll *a*	Chloro-phyll *b*	Total green	Cartoin	Xantho-phyll	Total yellow
ORB 79 ..	2·89	2·75	5·64	1·26	3·00	4·24
ORB 117 ..	3·21	2·32	5·53	1·50	4·10	5·60
CO 453 ..	7·07	2·80	9·87	3·70	6·50	10·20
CO 356 ..	5·70	1·20	6·90	3·20	5·20	8·40
CO 341 ..	3·80	3·29	7·09	2·18	2·90	5·08
CO 421 ..	4·76	4·10	8·86	2·17	3·45	5·62
CO 448 ..	5·31	4·25	9·56	3·86	4·72	8·58
ORB 191 ..	4·25	2·77	7·02	3·87	6·11	9·98

In another experiment, pigment content and pigment ratios were estimated in five sugarcane varieties—Co 453, Co 421, P.O.J. 2878, Co 205 and Rheora—grown under four distinct conditions of nutrition—complete nutrition, nitrogen deficiency, phosphorus deficiency, and potassium deficiency. Over-all nutrition values showed that the variety Co 453 excelled all others in certain directions, viz., chlorophyll *a*, chlorophyll *b*, carotin, total green pigments and total yellow pigments. Other pigment ratios, e.g., total yellow/carotin, total green pigments/chlorophyll *b*, chlorophyll *a*/chlorophyll *b*, chlorophyll *a*/carotin, were also slightly higher in this variety. Co 205 shew slightly higher ratios of total yellow/xanthophyll, total

TABLE 11.

Pigment content and pigment ratios in different sugarcane varieties in mgm. per 10 gm. fresh weight of leaves.

Varieties	Complete nutrition	−N	−P	−K	Mean
		Chlorophyll a			
Co 453	7·50	8·50	38·00	12·75	16·69
Co 421	5·90	7·80	5·40	9·25	7·09
P.O.J.2878	8·50	7·50	12·07	3·04	7·78
Co 205	8·45	6·95	8·56	21·25	11·30
Rheora	7·30	6·25	6·95	2·91	5·85
Mean	7·53	7·40	23·91	9·84	..
		Chlorophyll b			
Co 453	6·25	8·75	5·16	22·35	10·63
Co 421	7·25	7·30	4·55	7·60	6·70
P.O.J.2878	6·95	6·95	23·60	2·12	9·90
Co 205 . . .	10·25	8·25	8·78	4·15	7·86
Rheora	8·45	7·50	10·17	3·12	7·31
Mean	7·83	7·75	10·45	7·86	..
		Carotin			
Co 453	2·10	2·05	8·30	27·20	9·91
Co 421	2·40	2·00	11·35	14·83	7·64
P.O.J.2878	2·25	2·10	14·30	11·50	7·53
Co 205	1·95	3·35	9·35	5·45	5·02
Rheora	2·10	2·00	8·55	7·50	5·03
Mean	2·16	2·30	10·37	13·29	..
		Xanthophyll			
Co 453	3·15	2·73	22·35	11·80	7·50
Co 421	3·25	3·03	10·63	13·28	7·54
P.O.J.2878	3·75	3·60	9·70	10·04	6·77
Co 205	2·15	3·00	11·50	3·24	4·97
Rheora	3·04	2·63	12·35	9·70	6·93
Mean	3·06	2·99	13·30	9·61	..
		Total green pigments			
Co 453	13·75	17·25	43·16	35·10	27·32
Co 421	13·15	15·10	9·95	16·85	13·74
P.O.J.2878	15·45	14·45	35·67	5·17	17·68
Co 205	18·70	15·20	17·34	25·40	19·16
Rheora	15·75	13·75	17·13	6·03	13·16
Mean	15·36	15·13	24·65	17·71	..
		Total yellow pigments			
Co 453	5·25	4·78	30·65	39·00	19·92
Co 421	5·65	5·04	21·98	28·11	15·19
P.O.J.2878	6·00	5·70	24·00	21·54	14·31
Co 205	4·10	6·35	20·89	8·69	9·99
Rheora	5·14	4·63	20·90	17·20	11·96
Mean	5·22	5·30	23·67	22·90	..

TABLE 11 (*Contd.*)

Pigment content and pigment ratios in different sugarcane varieties in mgm. per 10 gm. fresh weight of leaves.

Varieties	Complete nutrition	—N	—P	—K	Mean
Total green pigments/chlorophyll a					
Co 453	1·83	2·03	1·13	2·75	1·93
Co 421	2·22	1·93	1·84	1·82	1·95
P.O.J.2878	1·81	1·93	2·95	1·70	2·09
Co 205	2·21	2·18	2·02	1·19	1·90
Rheora	2·15	2·20	2·46	2·07	2·22
Mean	2·04	2·05	2·08	1·90	..
Total green pigments/chlorophyll b					
Co 453	2·20	1·97	8·36	1·57	3·52
Co 421	1·81	2·06	2·18	2·21	2·06
P.O.J.2878	2·22	2·08	1·51	2·43	2·06
Co 205	1·82	1·84	1·97	6·12	2·93
Rheora	1·86	1·83	1·68	1·93	1·82
Mean	1·98	1·95	3·14	2·85	..
Total yellow/Carotin					
Co 453	2·50	2·33	3·69	1·43	2·48
Co 421	2·35	2·52	1·93	1·89	2·17
P.O.J.2878	2·66	2·71	1·67	1·87	2·22
Co 205	2·10	1·89	2·23	1·59	1·95
Rheora	2·44	2·31	2·44	2·29	2·37
Mean	2·41	2·55	2·39	1·74	..
Total yellow/Xanthophyll					
Co 453	1·66	1·75	1·37	3·31	2·02
Co 421	1·74	1·66	2·07	2·11	1·89
P.O.J.2878	1·60	1·58	2·47	2·14	1·90
Co 205	1·91	2·15	1·81	2·68	2·13
Rheora	1·69	1·76	1·69	1·77	1·90
Mean	1·70	1·78	1·88	2·40	..
Total green pigments/total yellow pigments					
Co 453	2·62	3·61	1·41	0·90	2·13
Co 421	2·32	2·99	0·45	0·59	1·58
P.O.J.2878	2·57	2·54	1·49	0·24	1·71
Co 205	4·55	2·39	0·83	2·92	2·47
Rheora	3·97	2·97	0·82	0·35	1·05
Mean	3·12	2·90	1·00	1·00	..
Chlorophyll a/chlorophyll b					
Co 453	1·20	0·97	7·36	0·57	2·52
Co 421	0·81	1·06	1·18	1·21	1·06
P.O.J.2878	1·22	1·08	0·51	1·43	1·06
Co 205	0·82	0·84	0·87	5·12	1·94
Rheora	0·86	0·83	0·68	0·93	0·83
Mean	0·98	0·95	2·14	1·85	..

TABLE 11 (*Concld.*)

Pigment content and pigment ratios in different sugarcane varieties in mgm. per 10 gm. fresh weight of leaves

Varieties	Complete nutrition	—N	—P	—K	Mean
		Chlorophyll b/Carotin			
Co 453	2·97	4·27	0·62	0·82	2·17
Co 421	3·02	3·65	0·40	0·51	1·89
P.O.J.2878	3·09	3·31	1·65	0·18	2·06
Co 205	5·26	2·46	0·94	0·76	2·36
Rheora	4·02	3·75	1·19	0·42	2·34
Mean	3·67	3·49	0·96	0·55	..
		Chlorophyll b/Xanthophyll			
Co 453	1·99	3·20	0·23	1·89	1·83
Co 421	2·23	2·41	0·43	0·57	1·41
P.O.J.2878	1·85	1·93	2·43	0·21	1·60
Co 205	4·77	2·75	0·76	1·28	2·39
Rheora	2·78	2·85	0·82	0·32	1·69
Mean	2·72	2·63	0·83	0·85	..
		Chlorophyll a/Carotin			
Co 453	3·57	4·14	4·57	0·47	3·19
Co 421	2·46	2·90	0·47	0·62	1·86
P.O.J.2878	3·78	3·58	0·84	0·26	1·86
Co 205	4·32	2·07	0·92	3·90	2·80
Rheora	3·47	3·12	0·81	0·38	1·95
Mean	3·52	3·36	1·52	1·13	..
		Chlorophyll a/Xanthophyll			
Co 453	2·38	2·47	1·70	1·81	2·09
Co 421	1·81	2·57	0·51	0·69	1·39
P.O.J.2878	2·26	2·08	1·24	0·30	1·47
Co 205	3·93	2·31	0·74	6·55	3·38
Rheora	2·41	2·38	0·56	0·30	1·41
Mean	2·56	2·36	0·95	1·93	..
		Carotin/Xanthophyll			
Co 453	0·66	0·75	0·37	2·30	1·02
Co 421	0·73	0·66	1·69	1·11	1·05
P.O.J.2878	0·60	0·58	1·47	1·14	0·95
Co 205	0·91	1·01	0·81	1·14	0·97
Rheora	0·69	0·76	0·69	0·77	0·73
Mean	0·72	0·75	1·00	1·29	..

green/total yellow, chlorophyll *b*/carotin, chlorophyll *b*/xanthophyll and chlorophyll *a*/xanthophyll than other varieties. The remaining three varieties were in general, poorer in the majority of the pigment ratios (Table 11). It was also significant to note that drought resistant *Rheora* showed the least content of chlorophyll *a*, total green pigments, total chlorophyll/chlorophyll *b*, total yellow/xanthophyll, total green/total yellow, chlorophyll *a*/chlorophyll *b*, and carotin/xanthophyll ratios.

Co 205 another variety tending towards drought resistance (Lal and Mehrotra, 1950) showed slightly lower concentration of carotin and xanthophyll, total yellow pigments, total chlorophyll/chlorophyll *a*, and total yellow/carotin ratios than other standard canes. Co 421 also evinced lower Chlorophyll *b*, chlorophyll *b*/carotin, chlorophyll *b*/xanthophyll and chlorophyll *a*/xanthophyll ratios. The drought susceptible P.O.J. 2878 showed more or less intermediate values between the other sugarcane varieties. How far chlorophyll *a* and poor total green pigments in Rheora were drought resistant characters would be analysed in later investigations.

(*f*) *Effect of Mineral deficiencies on pigment content and pigment ratios*:

Effect of nitrogen, phosphorus, and potassium deficiencies was analysed in pot cultures using sand medium where different conditions of mineral deficiency were maintained with the aid of Hoagland's solutions (Lal and Mehrotra, 1950). The effect of these nutrient deficiencies was analysed in five sugarcane varieties mentioned in Table 11 at maturity. Over-all varietal figures show that phosphorus deficiency markedly improved chlorophyll *a*/chlorophyll *b*, xanthophyll, total green pigments, total yellow pigments and chlorophyll *a*/chlorophyll *b* ratio. A marked improvement in green and yellow pigments and the relatively greater increase in chlorophyll *a* as compared to chlorophyll *b* was evident in phosphorus deficient leaves. Potassium deficiency was noted to improve carotin, total chlorophyll/chlorophyll *b*, total yellow/xanthophyll and carotin/xanthophyll ratios. No marked reduction in various green and yellow pigments or their ratios was noted in nitrogen deficiency. It thus became evident that while phosphorus deficiency improved green pigments, nitrogen deficiency failed to induce any marked alteration in various pigments under the conditions of sand nutrient cultures at maturity. As against these deficient cultures, fully manured canes shew the highest ratios of total green/total yellow, chlorophyll *b*/carotin, chlorophyll *b*/xanthophyll, chlorophyll *a*/carotin and chlorophyll *a*/xanthophyll. These plants also shew marked reduction in carotin, total yellow, total yellow/xanthophyll and carotin/xanthophyll ratios. Balanced nutrition, therefore, led to poorer yellow pigments and higher proportion of green pigments (Table 11).

(*g*) *Effect of leaf development on pigment content and pigment ratios*:

Pigment content of leaves of various stages of development collected from apex downwards on the main shoot of sugarcane was determined at 250 days in the life cycle, in variety Co 453 grown under field conditions. Chlorophyll *a* was highest in the second expanded leaf from the top; further advance in age reduced its concentration. Slight tendency to high chlorophyll *a* content in the oldest green leaf (fifth leaf) was also observed. With the onset of yellowing, chlorophyll *a* content shew a continuous decline in the sixth, seventh and eighth leaf (Fig. 3).

Chlorophyll *b* content was highest in the first and third leaves. Older leaves shew a decline in concentration of this pigment. Tendency to show high chlorophyll *b* in the sixth leaf was also noticeable. Seventh and eighth leaves shew disintegration of green pigments resulting in marked decline in chlorophyll *b*. Carotin and xanthophyll were highest in the fourth leaf. Sixth leaf also tended to show high content of these pigments. Further with advance in age, decline in total yellow pigments was less characteristic than the decline in the content of total green pigments.

Chlorophyll *a*/chlorophyll *b* and total chlorophyll/chlorophyll *b*, shew the same trend of variation with leaf development reaching a maximum in the fifth leaf. Total green/total yellow, chlorophyll *b*/xanthophyll, total yellow/xanthophyll and carotin/xanthophyll ratios also showed relatively high values for the third

leaf. Comparative figures shew relatively higher values for pigment content and pigment ratios in the third and fifth leaves. A general disintegration of green

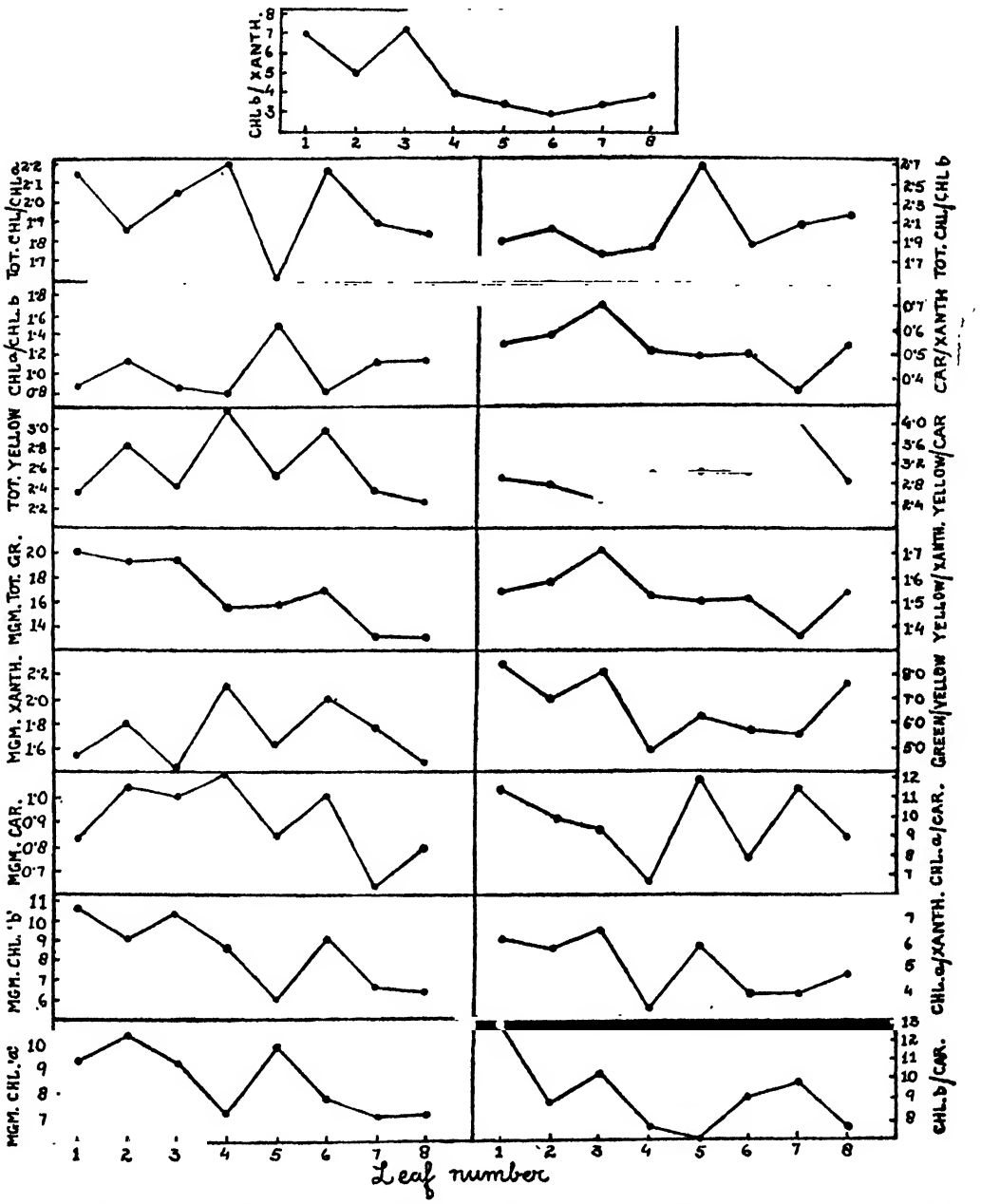

FIG. 3. Effect of increasing age of leaves, upon pigment content and pigment ratios of sugarcane leaves.

pigment as compared to the yellow pigments was observed with advance in age. Percentage decline in total green pigments between the young and old leaves was relatively higher than the fall recorded for the yellow pigments. Disintegration of chlorophyll started beyond the third leaf stage, while the yellow pigments declined only after the sixth leaf stage. Older leaves also shew higher proportion of total yellow/carotin ratio. This was in contrast to that obtained for total yellow/

xanthophyll ratio which shew a reverse course. A gradual fall in carotin more in proportion to xanthophyll was noticeable with advance in age after the third leaf stage reaching lowest carotin/xanthophyll ratio in the seventh leaf (Fig. 3).

Discussion.

Summarizing the evidences put forward in the previous pages on the effect of nutrients upon chlorophyll content of sugarcane leaves, it may be pointed out that this character was largely determined by the nutrition provided to the sugarcane crop. Relatively, application of nitrogen in local soils was more beneficial in increasing chlorophyll content than applications of either phosphorus and potassium as fertilisers. This was clearly evident from the results of experiments narrated in the previous pages. Lower doses of nitrogen were less effective than higher doses, of the order of 100 lbs. N. Phosphorus and potassium on the contrary, failed to bring about any significant response under conditions of pot cultures. In the field, however, phosphorus exhibited a slightly significant effect at 75 lbs. P_2O_5 level. Useful effect of nitrogen at 20 p.p.m. and of phosphorus at 5 p.p.m. have also been noted in pot cultures. Potassium on the contrary, proved deleterious under the conditions of pot culture. In sand medium, phosphorus and potassium exhibited tendencies to decrease the chlorophyll content of leaves. Increases above the basic level of phosphorus to 37·5 lbs. or to 75 lbs. P_2O_5 proved deleterious. Lower levels of potassium were equally harmful on chlorophyll content. Increase in potassium from 25 lbs. to 50 lbs. K_2O in soil, however, raised the chlorophyll content. A good ratio of NPK for high chlorophyll content was $N_2P_0K_2$ where the corresponding levels of nutrients were 150 lbs. N, and 50 lbs. K_2O without any added phosphorus.

Relatively, deficiencies of mineral ingredients also brought about marked reduction in chlorophyll. In general, the larger the deficiency of nitrogen the greater was the decrease in chlorophyll content during active growth period. When all the three ingredients N, P, and K were deficient, chlorophyll content was lowered to the maximum extent. Sufficiency of two or more elements was usually deleterious.

The deleterious effect of nitrogen starvation towards the end of the growth cycle in these investigations did not appear to be as characteristic as the effects of nitrogen starvation during early stages when significant reductions in chlorophyll were recorded. Phosphorus deficiency, on the other hand, shew characteristic effects in increasing the concentration of all the green and yellow pigments. How phosphorus deficient plants increased these pigments is yet unknown. Obviously, it pointed out the possibility that in presence of phosphorus, nitrogen could not be fully utilised in increasing the chlorophyll content; in absence of phosphorus, relative abundance of nitrogen enabled the latter to be utilised more in the formation of these pigments. Further light on this point would be thrown in a later communication. As against these two deficiencies, absence of potassium caused an increase in concentration of carotin; a higher proportion of carotin relative to xanthophyll was formed. A comparison of the effects of three deficiencies shew that phosphorus deficiency was more helpful from the point of view of chlorophyll. This is why a phosphorus deficient crop looked more deep dull green in contrast to the bright greenish colour of leaves in the normal fed plants.

The data further led to the view that chlorophyll content was governed by the total nutrition provided to the crop. By total nutrition is meant the total concentration of N, P, and K supplied to the culture medium. In general, among all the twenty cultures investigated (Table 3) highest chlorophyll content was recorded in cultures where the total nutrient concentration was 50–70 p.p.m. Higher concentrations shew deleterious effects in some cases (potassium cultures) and less

so in others (nitrogen and phosphorus cultures). If the proportion of nitrogen in the total nutrition provided was below 33 per cent, chlorophyll content was markedly reduced. If it was higher, within the range of 40 to 50 per cent of total concentration, slightly harmful effects were observed. Nitrogen higher than 33 per cent of the total concentration of NPK in other words, did not limit chlorophyll formation. Proportions lower than this initial limit on the contrary, exhibited a state of poverty adjustment for chlorophyll formation. Similar critical limits for phosphorus was a concentration of 28 per cent in the total NPK concentration. Above and below this level, states of luxury consumption and poverty adjustments were noticed. In the case of potassium, increases beyond 5 per cent exhibited luxury consumption of this element. A proportion of N : P : K in the ratio of 33 : 28 : 5 per cent of total concentration appeared to be a safe ratio for maximum chlorophyll formation under conditions of pot culture.

The data further indicated that a total salt concentration of 60 p.p.m. and above was found to be helpful in raising the chlorophyll content of leaves provided nitrogen formed one of the main constituents of the nutrition provided (Table 3). Concentrations lower than this were decidedly harmful. The average figures for different cultures indicated that a higher proportion of nitrogen than either phosphorus or potassium was required for inducing high chlorophyll content. Nitrogen between 50–66 per cent of total nutrition induced highest chlorophyll content.

Comparative analysis of these responses indicated that above 66 per cent nitrogen invariably shew luxury consumption and below 33 per cent of the total nutrition in the medium, it exhibited the state of poverty adjustment. Within this range of 33–66 per cent chlorophyll content appeared to be somewhat determined by the concentration of other nutrients in the culture medium. Relatively, nitrogen was the most important. Even in the absence of P and K a moderate supply of nitrogen within the range indicated, was sufficient to induce high chlorophyll content.

Summary.

This paper deals with the relative effects of nitrogen, phosphorus and potassium applied in various ratios and proportions, effects of organic and inorganic fertilisers, relative sufficiency and deficiency effects of the N, P, and K, and effects of age and development on the chlorophyll content of leaves of sugarcane. The investigations were conducted in pots and under field conditions and portray the results obtained during the past fourteen years in this laboratory.

Chlorophyll content was markedly affected by the conditions of nutrition provided to the sugarcane plant. Relatively nitrogen was more effective in increasing chlorophyll than either phosphorus or potassium. Of these three ingredients, deficiency of nitrogen lowered chlorophyll content. Phosphorus deficiency raised the chlorophyll pigments even beyond the control and shew states of better utilisation of nitrogen in the formation of the green pigment. Potassium starvation shew symptoms similar to that of deficiency of phosphorus but the improvements in the pigments were of lower degree.

Various forms of inorganic and organic fertilisers altered chlorophyll content but no consistency in results was recorded in response to either of them. Mixtures did not exhibit any distinct effect, though a mixture of half and half niciphos and blood meal at an early stage proved more helpful than others.

Advance in age of leaves decreased chlorophyll content after the fifth leaf stage. Total yellow pigments on the other hand, increased up to the fourth leaf from top and thereafter declined. The decline in green pigments was more than in the yellow ones; disintegration in the former started earlier than in the latter. A gradual fall in carotin more than in xanthophyll was noted with advance in age.

Chlorophyll content was markedly determined by the total concentration of all the nutrients and the percentage proportion of individual ingredients, nitrogen, phosphorus and potassium, in the total nutrition provided to the crop. Critical limits of nitrogen appeared to be 33 per cent of the total concentration below and above which this ingredient exhibited states of poverty adjustment and luxury consumption respectively. Within this range of 33–66 per cent, response was regulated by the presence of other complimentary factors in the culture medium. For high chlorophyll, a total concentration of 66 p.p.m. of added nutrients was the optimum requirement with the nitrogen forming one of the main ingredients in the ratio of N : P : K :: 33 : 28 : 5 in the nutrition applied.

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BAND SPECTRUM OF CARBON-DISULPHIDE, PART III.

C. RAMASASTRY, *D.Sc.* (*lately I.C.I. Research Fellow, N.I.S.I., Department of Applied Physics, Andhra University, Waltair*), *Department of Physics, Indian Institute of Technology, Kharagpur.*

(Communicated by Prof. K. R. Rao, F.N.I.)

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In Part II (Ramasastry, 1952), it is outlined that the method adopted to get at the vibrational analysis of the near ultraviolet absorption bands of carbon-disulphide is to consider the possibility of finding two overlapping band systems in the region $\lambda 3800 - \lambda 2900$ and to try as far as it is possible experimentally to isolate bands belonging to the two systems. In the same paper evidence was presented to ascribe most of the bands in the violet end from $\lambda 3300 - \lambda 2900$ of the absorption spectrum to an electronic transition $^{\cdot 1}A_2 - ^{\cdot 1}A_1$ (Plate I*a*, *b*, *c* of this paper). Bands at the other end of the spectrum in the region 3800A—3500A (Plate I*f*) will now be considered as most of them are likely to belong to another electronic transition $^{\cdot 1}B_2 - ^{\cdot 1}A_1$. The over-lapping region between 3500A—3250A (Plate I*d*, *e*) will be analysed in a subsequent communication.

The development of the absorption in the entire region 3800A–2900A is presented in Plate XIX. The various strips are reproductions from Medium Quartz spectrograms. Plate XX shows a Quartz Littrow spectrogram obtained at on metre absorption tube length containing CS_2 at the saturation vapour pressure at 27°C. The bands are traceable up to 3815A while one countenances continuous absorption below 3500A. Remembering that progressions with an interval of about 270 cm.$^{-1}$ were noticed by earlier investigators in this region, the following series can be presented on the basis of the relative intensities and the positions of the members.

	v_2'	I		II		III		IV
	0	26203	398	26601	411	27012		27408–'390
(294)		294		294		299		
	1	26497	399	26896	415	27311	388	27699
(290)		291		290		290		289
	2	26788	397	27185	414	27599	389	27988
(283)		282		284		282		282
	3	27070	399	27469	413	27882	389	28271
(274)		274		272		274		274
	4	27344	397	27742	414	28156	390	28545
(270)				268				272
	5	27598–'626		28010		28410–'426		28817
(268)				268				
				28279		28699		29082–'094

Progressions II, III and IV were noticed only in part by the earlier investigators. Progression I and its relation to progression II are newly brought out. Undoubtedly these two progressions are related to each other by the bending vibration ($\nu_2'' = 398$) of the ground state. Following Lieberman (1941) and

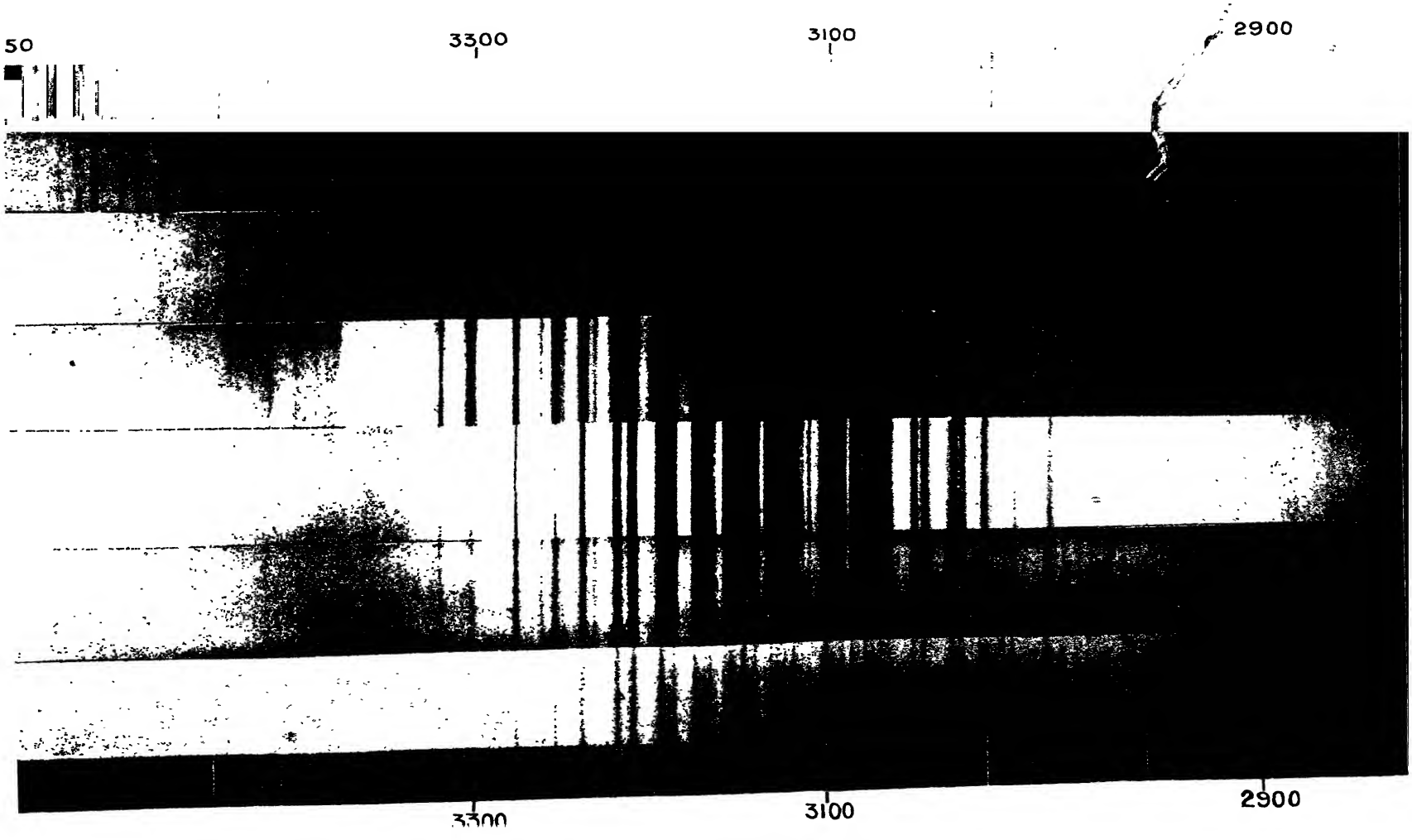
Mulliken (1941), taking it for granted that the molecule is linear in its lower (ground) electronic state and that the members of progression IV arise from vibrationless ground level $^1\Sigma_g^+$, one has to explain the above progressions as due to transitions from both $^1\Sigma_g^+$ and $^1\Pi_u$ type lower levels to one and the same set of upper levels. The interpretation of progression III as progression IV$-\nu_2''$ is however somewhat uncertain because of numerical discrepancy; nevertheless, the unmistakable presence of progression I and its displacement from progression II by ν_2'' necessitates the interpretation that they arise from two $^1\Pi_u$ lower state levels of the deformation vibration to one and the same set of upper state levels. Such transitions are not allowed by the selection rules enunciated by Mulliken for the $^1B_2-^1\Sigma_g^+$ electronic transition.

As it is almost certain that the electronic transition is between a linear lower state and a considerably bent upper state, the symmetry elements common to both the point groups $D_{\infty h}$ and C_{2v} need only be considered to arrive at the allowed transitions. As C_{2v} is a sub-group of $D_{\infty h}$, the linearity of the molecule in its ground state is to be considered as a particular (special) case of the bent condition for purposes of this transition. Both ν_1 and ν_2 vibrational modes of the lower state will then have to be considered as totally symmetrical (they are already totally symmetrical in the upper state).

The transition now falls into line with Herzberg and Teller's selection rules. It is very much similar to the near ultraviolet transition in SO_2 (Metropolis, 1941), where the bond angle has changed considerably due to the electronic transition and made extensive progressions in ν_2' possible. From these considerations one can always look for bands displaced to the low energy side of the above mentioned progressions by the amounts $n\times 656+m\times 400$ where n and m are integers 0, 1, 2, 3 etc. Accidental locations can be eliminated from intensity considerations.

However, in view of the fact that Mulliken's selection rules were found to hold good to a large extent in the case of the short wavelength system represented by $^{\prime 1}A_2-^{\prime 1}\Sigma_g^+$ electronic transition, it will be interesting to see how far the rules for the $^{\prime 1}B_2-^{\prime 1}\Sigma_g^+$ transition are obeyed among the long wavelength bands. Liebermann's identification of progression IV as $(0\,v\,0)'-(0\,0\,0)''\,^1\Sigma_g^+$ and of progression II as $(0\,v\,0)'-(0\,2\,0)''\,^1\Sigma_g^+$ may be retained. Then progression I should be interpreted as $(0\,v\,0)'-(0\,3\,0)''$. Its appearance is against the selection rules; nevertheless the progression is present in an unmistakable manner. If these rules are completely violated, progression $(0\,v\,0)'-(0\,1\,0)''$ should also be expected with sufficiently high intensity and displaced from progression IV by -398 cm.$^{-1}$. But the observed progression in this region namely progression III is displaced only by -388 cm.$^{-1}$ from progression IV. The discrepancy of about 10 cm.$^{-1}$ can hardly be accounted for by errors in measurement. Turning to Mulliken's selection rules, one finds that $(0\,v^0\,0)'-(0\,0^0\,0)''$ is allowed while $(0\,v^0\,0)'-(0\,1^1\,0)''$ is forbidden. On the other hand, $(0\,v^1\,0)'-(0\,1^1\,0)''$ is permitted. (The numeral on the central quantum number indicates the gyrovibronic quantum number K in the bent upper state and the azimuthal quantum number l for the linear lower state as in Part II.)

Thus progression III can be labelled as $(0\,v^1\,0)'-(0\,1^1\,0)''$ with a good deal of justification. The levels $(0\,1^1\,0)''$ and $(0\,0^0\,0)''$ of the ground state are known to be placed 398 cm.$^{-1}$ apart while progression IV and III are separated by 388 cm.$^{-1}$ only. This difference of about 10 cm.$^{-1}$ will be the separation between the levels $(0\,v^1\,0)'$ and $(0\,v^0\,0)'$ of the upper electronic state and is to be ascribed to the gyrovibronic energy with $K=1$. Taking this energy to be given by the expression $CK(K+1)$, we have $C=5$ which corresponds to the B value for rotation about the axis of least movement of inertia in the bent molecule. Having


50
3300
3100
2900
3300
3100
2900

evaluated C, one can approximately predict the location of the progression $(0\ v^2\ 0)$, $(0\ 2^2\ 0)''$ which again is allowed by Mulliken's selection rules. It should be displaced from progression IV $[(0\ v^\circ\ 0)'-(0\ 0^\circ\ 0)'']$ by $-2\nu_2''+CK(K+1) = -796 +30 = -766$ cm.$^{-1}$ (taking $K=2$) approximately. Such bands are in fact observed at the expected positions, quite prominent and intense. These are 26994, 27226, 27513, 27776, 28041 and appear on the short wavelength side of the members of progression II $[(0\ v^\circ\ 0)'-(0\ 2^\circ\ 0)'']$. These new bands will be designated as II-a progression.

The above analysis explains most of the intense bands in the region 3800A–3550A. The exceptions should now be mentioned. It has already been remarked that the appearance of progression I is against Mulliken's selection rules. It may, however, be noted that in this progression the most intense band is ν 27070 with $\Delta v_1 = \Delta v_2 = \Delta v_3 = 0$.

Bands 26176, 26461, 26747 are located at -1523 (ν_3'') from the corresponding numbers in progression IV. Their appearance is forbidden by both Mulliken's and Herzberg and Teller's selection rules. But these bands are, however, very weak.

A search has been made for bands shifted to the low energy side of the intense bands by the various values of the ground state vibrational energies. The values tried are 398, 656, 800, 1056, 1312, 1456, 1523 and 1600 and the results are given in Table II.

It is interesting that there are no bands, even very weak ones, displaced by -398 cm.$^{-1}$ either from members of progression III or progression II-a. Two weak bands, 27868 and 28143 are located at -403 and -402 cm.$^{-1}$ from 28271 and 28545 of progression IV and a very weak band 26670 can be represented by $(0\ 3\ 0)'$—$(0\ 4\ 0)''$.

A superposition of the totally symmetrical vibration v_1'' on the lower states of any one of the above-mentioned five progressions will not alter the species character of those states. The Boltzman factor for this vibration is 1/23. The expected positions of the -656 bands of progression IV fall on the R-branches of the members of progression III which, arising as it does from the $(0\ 1\ 0)''$ level should be more intense both from the point of view of Boltzman factors and F-C Principle for transitions to a bent upper state from a linear state. It is on the whole observed that the bands involving ν_1'' vibration are rather very few and weak. It may be that when excited in combination with other vibrations of the ground state it might have changed its magnitude that it could not be easily picked up and/or the transition probabilities considerably fall down when this vibration is excited in the ground state. In the region studied, there are no other progressions sufficiently long to justify the detection of another frequency of the upper electronic state; in particular ν_1' could not be calculated. If as a result of the electronic transition the internuclear distance were changed, the ν_1' and ν_1'' should appear prominently in progressions. From the absence of these and the predominence of ν_2' progressions it may be suggested that in the upper electronic state of these absorption bands the CS_2 molecule is considerably bent while the C-S internuclear distance remained sensibly unaltered.

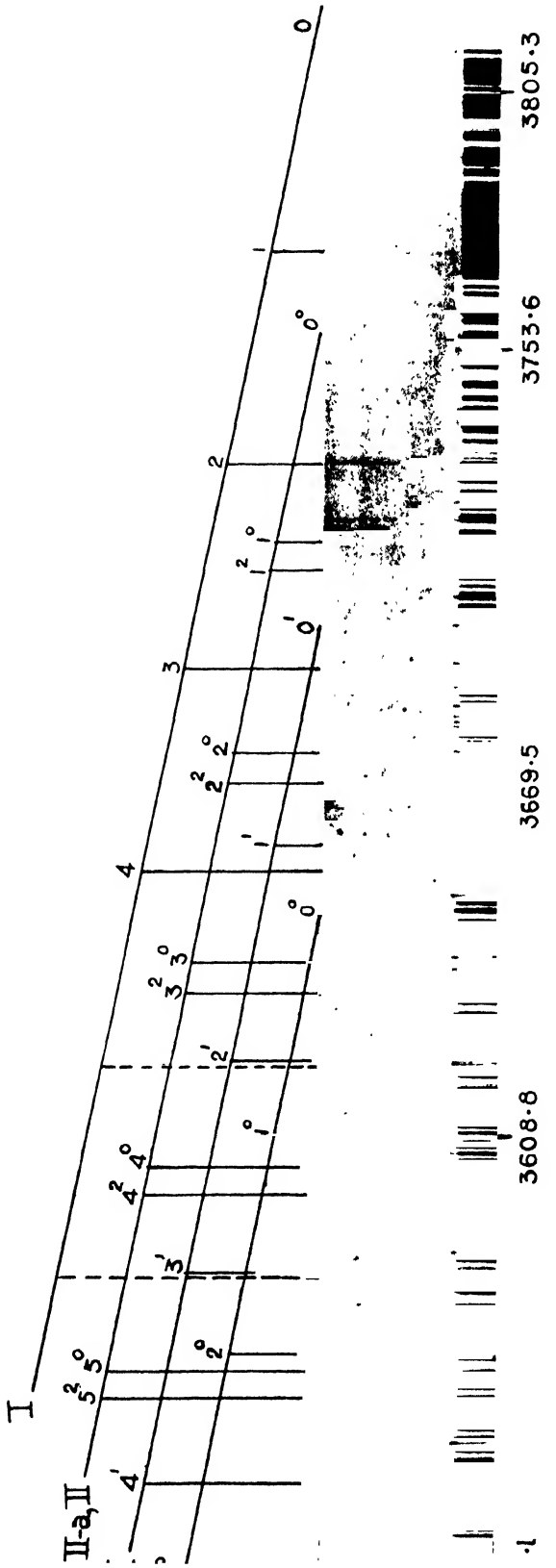
A passing mention may be made of the other possible interpretations of the various progressions. The interval 414 cm.$^{-1}$ between the progressions II and III may be regarded as ν_1' of the upper state. Then progression III will be $(1\ v\ 0)'$ —$(0\ 2\ 0)''$ instead of as $(0\ v\ 0)'-(0\ 1\ 0)''$. Similar 414 cm.$^{-1}$ progression should also be found associated with progression IV. But such a one is not present. There is also no immediate explanation of progression II-a and this 414 cm.$^{-1}$ interval has not been frequently met with among the other bands. Further, the absence of $(0\ v\ 0)'$—$(0\ 1\ 0)''$ should be regarded as due to the forbidden nature of the transition and the presence of $(0\ v\ 0)'$—$(0\ 3\ 0)''$ as an exception considering its weakness. To meet this anomaly one may represent progression II itself as the $(0\ v\ 0)'$—$(0\ 0\ 0)''$,

progression I as $(0\ v\ 0)'$—$(0\ 1\ 0)''$, progression III as $(1\ v\ 0)'$—$(0\ 0\ 0)''$ and progression IV as $(2\ v\ 0)'$—$(0\ 0\ 0)''$. This leads to $\nu_1' = 414$ cm.$^{-1}$ and $2\nu_1' = 801$ cm.$^{-1}$ and the discrepancy may be explained as due to the repulsion between the energy levels $2\nu_1' = 828$ and $3\nu_2' = 867$. Then the whole thing will be in agreement with Herzberg and Teller's selection rules for transition from linear lower to bent upper state as outlined earlier. But then it would be difficult, with the help of the above-mentioned repulsion, to explain the observed decrease in the intervals of the ν_2' progressions as it would indicate sudden increase in these intervals at the repelled levels. There is thus not enough justification to disregard the numerical agreement of 801 cm.$^{-1}$ with the $2\nu_2''$ of the ground state.

Coming back at this stage to the earlier analysis based on Mulliken's selection rules, it is worth while reconsidering the relative intensities of the various progressions though this has already been done to some extent by Lieberman and Mulliken. The populations of molecules in the various vibrational levels of the ground electronic state are governed by the Boltzman factors. In addition, for the bending vibration which is two-fold degenerate the vth level has the statistical weight $(v+1)$. The relative proportion of the molecules in the initial levels (000)—0, (010)—398, (100)—656, (020)—801, (030)—1200, and (001)—1523 are as 1: 1/3·3; 1/23: 1/15·7: 1/78·8: 1/1483. The high intensity of bands arising from levels with large energies of the bending vibration is very striking. The intensity of an absorption band is dependent on (*a*) Boltzman factors (*b*) Statistical weight (*c*) transition probability which is determined by the Frank-Condon principle. Liebermann pointed out that the —800 progression (II) is one-fifth or one-sixth as intense as the $(000)''$ progression (IV). The first two factors could account for an intensity of one-fifteenth only. The additional intensity has got to be ascribed to an increase in the transition probability. This increase is probably because, from the consideration of the F-C principle, the transition to a bent upper state is more favoured if a bending vibration is excited in the lower linear state of the molecule.

The gradual decrease in the intervals between successive members in the ν_2' progressions may partly be due to anharmonicity. If one tries to extend these progressions further than is shown, one encounters a strong band with a sudden decrease in the interval, e.g. at 28410 and 29082. In the present work progression II could be traced to its first member at 26601. The expected position of the sixth member of progression I falls in the degradation of an intense band 27598–27626 whose peak at 27601 is already included as the third member of progression III. So, due to the overlapping of higher members of falling intensity on the intense bands of progression III, progression I could be extended up to its fifth member only.

λ_{Wilson}	Int.	ν_{Wilson}	ν_{Author}		Assignment
			261761	VVW	(0 1 0)–(0 0 1)
			26203	VW	(0 0 0)–(0 3 0)
86·11	1	26404·9	26406	W	
83·9	1	26420		VVW	(0 3 0)–(1 3 0)
			26461	VW	(0 2 0)–(0 0 1)
73·0	1	26497	26497	W	(0 1 0)–(0 3 0)
69·8	1	26519	26518	VW	R-Branch.
			26549	VW	(0 2 0)–(1 2 0)
			26571	W	(0 3 0)–(2 1 0)
			26586	W	
			26601	W	(0 0 0)–(0 2 0)
			26632	W	
3751·5	1	26648	26648	W	
			26670	VW	(0 3 0)–(0 4 0)
			26689	W	
3737·6	1	26747		VW	(0 3 0)–(0 0 1)
31·96	1	26788·0	26788	W	(0 2 0)–(0 3 0)


3805·3
3753·6
3669·5
3608·8
I
II-a,II

λ_{Wilson}	Int.	ν_{Wilson}	ν_{Author}		Assignment
37[illegible]·14	1	26865·9	26865	W	
18·9[illegible]	1	26881·6	26882	W	
16·97	1	26896·0	26896	W	(0 1 0)–(0 2 0)
11·77	1	26933·7	26934	W	(0 1^2 0)–(0 2^2 0)
			26950	VW	
			26957	VW	
			26990	VW	
			27013	W	(0 0^1 0)–(0 1^1 0)
[illegible]93	1	27069·5	27071	Str	(0 3 0)–(0 3 0)
			27085	W	
81·87	1	27152·4	27152	W	
79·98	1	27166·3	27167	W	
77·43	1	27185·2	27185	Str	(0 2 0)–(0 2 0)
75·88	1	27196·6	27196	VW	
71·91	1	27226·0	27226	Str	(0 2^2 0)–(0 2^2 0)
70·93	1	27233·3	27233	W	
64·62	1	27280·2	27279	W	
			27286	VW	
60·2	1	27313	27310	W	(0 1^1 0)–(0 1^1 0)
59·3	1	27320	27315	W	
56·05	1	27344·1	27344	W	(0 4 0)–(0 3 0)
54·17	1	27358·2		W	
3646·38	1	27416·7	27390 }		(0 0 0)–(0 0 0)
			27412 }	W	
45·12	1	27426·1	27427	W	
			27431	W	
39·52	1	27468·4	27469	Str	(0 3 0)–(0 2 0)
			27476	W	
35·52	1	27498·6	27497	W	
34·16	1	27508·9	27511	Str	(0 3^2 0)–(0 2^2 0)
26·72	1	27565·3	27566	W	
22·42	1	27598·0	27600	V Str	(0 2^1 0)–(0 1^1 0)
21·1	1	27608			(0 5 0)–(0 3 0) or R-Branch
			27680	W	
			27694	W	
			27699	W	(0 1 0)–(0 0 0)
			27731	W	
03·59	1	27742·2	27742	Str	(0 4 0)–(0 2 0)
01·58	1	27757·6		W	
00·46	1	27766·3		W	
3599·14	1	27776·5	27776	Str	(0 4^2 0)–(0 2^2 0)
97·53	1	27789·0			
91·95	1	27832·1	27831	W	
89·85	1	27848·4	27849	W	
88·32	1	27860·3	27860	W	
87·32	1	27868·0		W	(0 3 0)–(0 1^1 0)
85·62	1	27881·2	27883	Str	(0 3^1 0)–(0 1^1 0)
83·72	1	27895·9			
79·30	1	27930·5	27933	W	
74·81	1	27965·3	27963	W	
73·26	1	27977·7	27978	Str	
72·00	1	27987·6	27987	Str	(0 2 0)–(0 0 0)
70·10	1	28002·5		W	
69·15	1	28009·9	28011	W	(0 5 0)–(0 2 0)
68·0	1	28019		W	
66·85	1	28028·0			
65·17	1	28041·2	28041	W	(0 5^2 0)–(0 2^2 0)
59·96	1	28082·2	28083	Str	
56·26	1	28111·4		W	
54·39	1	28126·2		W	
52·29	1	28142·8	28143	W	(0 4 0)–(0 1^1 0)
50·67	3	28155·7	28156	V Str	(0 4^1 0)–(0 1^1 0)

The band head data obtained from Hilger Quartz Lithrow spectrograms are used in the vibrational analysis and the vibrational frequencies derived are given below.

Upper state.				Lower state.	
(0 0 0)	0	(0 0^1 0)	9	(0 0 0)	0
(0 1 0)	294	(0 0^2 0)	30	(0 1 0)	398
(0 2 0)	584			(0 2^0 0)	801
(0 3 0)	868			(0 2^2 0)	796
(0 4 0)	1141			(0 3 0)	1198
(0 5 0)	1409			(0 4 0)	1600
(0 6 0)	1678				

The author is grateful to Prof. K. R. Rao for his interest in the work and Dr. D. S. Kothari for his encouragement. His thanks are due to the National Institute of Sciences of India for the award of I.C.I. (India) Research Fellowship during which period this work was carried out.

Abstract.

The near ultraviolet absorption bands of CS_2 in the region 3800A–3550A are examined in the light of Mulliken's selection rules for $^1B_2$–$^1A_1$ electronic transition between a bent upper state and a linear lower state. Five Progressions of bands each consisting of about 6 to 8 bands and involving intervals of 294 to 270 cm.$^{-1}$ are attributed to the ν_2' vibration. Some of these progressions which were observed in part by the earlier investigators are considerably extended and systematised. The (0 0 0)′–(0 0 0)″ transition is located at ν 27404 in the 3650A region.

Retaining Liebermann's interpretation of two of these progressions, the various progressions, separated from the (0 v 0)′–(0 0 0)″ by 388, 800, 770 and 1200 cm.$^{-1}$, are represented as (0 v^1 0)′–(0 1^1 0)″; (0 v^0 0)′–(0 2^0 0)″; (0 v^2 0)′–(0 2^2 0)″, and (0 v 0)′–(0 3 0)″; the last one however is forbidden by these selection rules (the top numerals on the central quantum numbers indicate the gyrovibronic quantum number K in the bent upper state and the azimuthal quantum number l in the linear lower state).

Expressing the gyrovibronic energy as $CK(K+1)$, the constant C could be assigned an approximate value of 5 cm.$^{-1}$

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Ramasastry (1952). Band Spectrum of Carbon-di-Sulphide, Part II. *Proc. Nat. Inst. Sci. Ind.*, **18**, 177–185.

* Earlier references are given in this part.

A PRELIMINARY STUDY OF THE FISH POPULATIONS ALONG THE MALABAR COAST.[1]

By B. S. BHIMACHAR, *F.N.I.*, *and* G. VENKATARAMAN, *Central Marine Fisheries Research Sub-Station, Calicut.*

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INTRODUCTION.

The study on the inshore fish population of the Malabar Coast was undertaken with a view to ascertaining the species of fishes occurring in the coastal waters, their relative intra- and inter-specific fluctuations at different times of the year, their sizes, sex proportions, maturity, life histories and their behaviour in relation to the biological and physico-chemical environment. It is intended to form an introduction to the detailed investigations on the biology and bionomics of individual species of food fishes of this coast. In this communication data collected by an analysis of weekly fish collections made for a year from April, 1949 to March, 1950 in the inshore area of the sea near West Hill along the Malabar Coast, together with a few tentative observations on them are presented. Not until the data on fish populations over a longer period are collected will it be possible to discuss in detail the various problems connected with this study and to draw such correlations as may exist between the behaviour of the fish stocks and the environmental factors.

Study of the fish populations on the lines mentioned above is a new aspect of fishery biology, in which the work of Warfel and Merriman (1944 and 1948) on the analysis of fish populations in the American waters deserves special mention. The methods and problems have been clearly stated by these authors, whose contributions form a good basis for further work and they have also been discussed in detail in the nine papers on 'A Symposium on Fish Populations' published in the Bulletin of the Bingham Oceanographic Collection (1948) and by Kesteven (1950). Day (1865), in his classical work on the 'Fishes of Malabar', has given a systematic account of the different species of this area. Chidambaram and Venkataraman (1946) and Devanesan and Chidambaram (1948) have given some facts relating to the natural history and economic aspects of some of the fishes of this coast. In a recent paper Kow (1950) has given some valuable information on the inshore fisheries of Singapore Straits.

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[1] Published with the permission of the Chief Research Officer, Central Marine Fisheries Research Station, Mandapam Camp, S. India.

Material and Methods.

For fish collections utilised in this study, two of the most common types of nets of this coast, namely, the boat seine (*Paithuvala*) and the gill net (*Chala vala*) were used. The fishing operation with each net was carried out once a week between 6 a.m. and 9 a.m.; the actual time taken for fishing was one-and-a-half hours. The composite catch for each net was brought to the laboratory for analysis.[1] The reason for using two nets for sampling the population is given on page 642. The boat used for fishing was the rowing dug-out canoe 30 feet long, 3 feet wide and 2½ feet deep, which is the most common boat used for commercial fishing operations along this coast. Four departmental fieldmen, who are expert fishermen, were engaged in fishing. Two canoes were used while operating the boat seine. In order to understand the significance of the use of two different types of nets it would be necessary to give a brief description of the nets used.

The boat seine (*Paithuvala*) is a flat conical cotton net, 25 feet long, the hinder portion of which is a wide-mouthed bag. The bag portion of the net is 12 feet long and tapers backwards to the cod end and widens anteriorly where it opens by a wide mouth. The mesh at the anterior portion of the bag is ½" bar and at the cod end it is ⅛" bar. The floor of the bag extends forwards into a wide platform 13 feet long and 40 feet wide at the anterior margin. The mesh of the platform portion is ½" bar. When the net is operated the sides of this platform are lifted up which drive the fish into the bag. To the front margin of the net is attached wide meshed coir netting as two tapering wings each 24 feet long. To the tapering anterior ends of these are fastened long ropes with which the net is dragged from the two boats. When the net is shot the mouth of the bag is opened by floats fastened to the head rope. On the foot rope of the coir wings are tied weights to sink the net. The net can be operated at any depth by adjusting the floats and weights.

To begin with the two boats are brought close to each other and half the net is taken in each boat. Then the boats are rowed and as they diverge from each other the net is shot from both the boats and when the end of the warp is reached, it is tied to one of the cross planks of the boat and the crew row the boats fast dragging the net at the required level. The net is hauled by drawing the warps. By the time the cod end of the net is drawn the two boats would have come close to each other. The fish caught are then transferred to the boat. The net is shot and hauled again in the same manner. Nets of more or less the same design but of bigger dimensions are used in commercial fishing along the coast.

The gill net used is locally called *Mathi chala vala*. It is a flat rectangular cotton net 50 feet long and 15 feet broad with mesh size ⅝" bar. Seven such pieces are laced together end to end. It is a floating net; floats are provided on the head rope and light weights on the foot rope at regular intervals and the net is shot in straight line. After the scheduled time the net is hauled and the gilled fishes removed from the net.

The weekly collections of fish brought to the laboratory were analysed for species, total weight, weight of individual species, their sizes, and sex proportions, wherever possible. The post-larvae which were obtained in large numbers during certain months were also studied in detail by another team. Each day a few specimens were examined in detail for stomach contents, gonad condition, etc., Total measurement of fish from the tip of the snout or the lower jaw whichever is longer to the end of the caudal fin, where the longer fluke is brought in alignment with the long axis of the body if the caudal fin is forked, was taken and recorded in millimetres. The other forms such as prawns, crabs, cuttle-fishes, *Squilla* and jelly fishes collected in the fishing nets and which along with the fishes form the biota of the inshore area were also analysed and recorded. The data for each day

[1] Analyses of individual fish hauls have been carried out in subsequent years.

were tabulated and recorded together with details of conditions of the sea and weather and records of salinity and temperature.

As a result of the discussion which followed the reading of this paper at the Indo-Pacific Fisheries Council Meeting held at Madras during February 1951, it was suggested that studies be made on the variability of the catches taken from various populations by certain methods and under specific conditions and that coefficients of variability be calculated in respect of certain factors as a means of selecting the most significant method for prolonged study. Based on this suggestion, a detailed programme of sampling the population with the method described in this paper was formulated and carried out during 1951-52. For purpose of taking the samples the inshore area was arbitrarily divided into 3 zones, namely 2, 4 and 6 fathom zones. In each zone 3 samples were taken at a time. The two nets, the boat seine and the gill net, were operated simultaneously for 15 minutes at each station. The collections were made between 6 a.m. and 10 a.m. and the fishing effort was constant throughout the period of this study. The 18 samples taken on each occasion were brought to the laboratory and analysed separately for total weight, species, weight and number of individual species, their sizes, etc.

The data collected so far in this study have shown that while there was some variability between the samples taken in the different zones in respect of species, their numbers and total weights, the successive hauls taken in one and the same zone tended to be almost similar to one another in all respects, variations between them being practically negligible. The variability between the replicate hauls taken in the same zone was not significant. This clearly indicates that the method of sampling the population used in this study can be relied upon to give satisfactory results in such studies.

Locality.—The fish samples were taken in the inshore area between two and four fathom lines near West Hill (Lat. 11° 17′ N., Long. 75° 46′ E.). The four fathom line is about two miles from the shore. This area is an open sea and is the eastern border of the Laccadive Sea. The coast line is straight. The sea is very calm except during June, July and August which is the period of South-West Monsoon. The sea bottom which is composed of soft clay is stirred up during the early part of the monsoon and settles down soon after.

Analysis of fishes and other animals.

51,700 specimens of fishes were collected during the year which belong to 14 orders, 37 families, 57 genera and 85 species, a list of which is given in Appendix 1. Appendix 2 gives monthly totals of the number of each species caught by the two nets. Those species which were represented by less than 10 specimens for the whole year are collectively included in the column—Other species.

A brief account of the important species which occurred commonly during the year is given below with special reference to their numbers, sizes and seasonal fluctuations.

Clupeidae.

The most abundant clupeids occurring in the inshore area during the year were *Kowala coval, Opisthopterus tardoore, Sardinella fimbriata* and *Pellona ditchoa.*

Fig. 1[1] shows the variation in abundance of *Kowala coval, Sardinella fimbriata* and *S. longiceps* during different parts of the year. All these species taken as a whole appeared abundantly during October, November and December and to a smaller degree in April-May. *Kowala coval,* popularly known as the white sardine was one of the most common species occurring in the inshore area. The peak of

[1] In figures 1 to 8 specimens less than 5 in number have been omitted.

occurrence was during the months of October and November. Specimens of size range 9·5 to 11·5 cms. with a narrow modal size range of 10 to 10·5 cms.

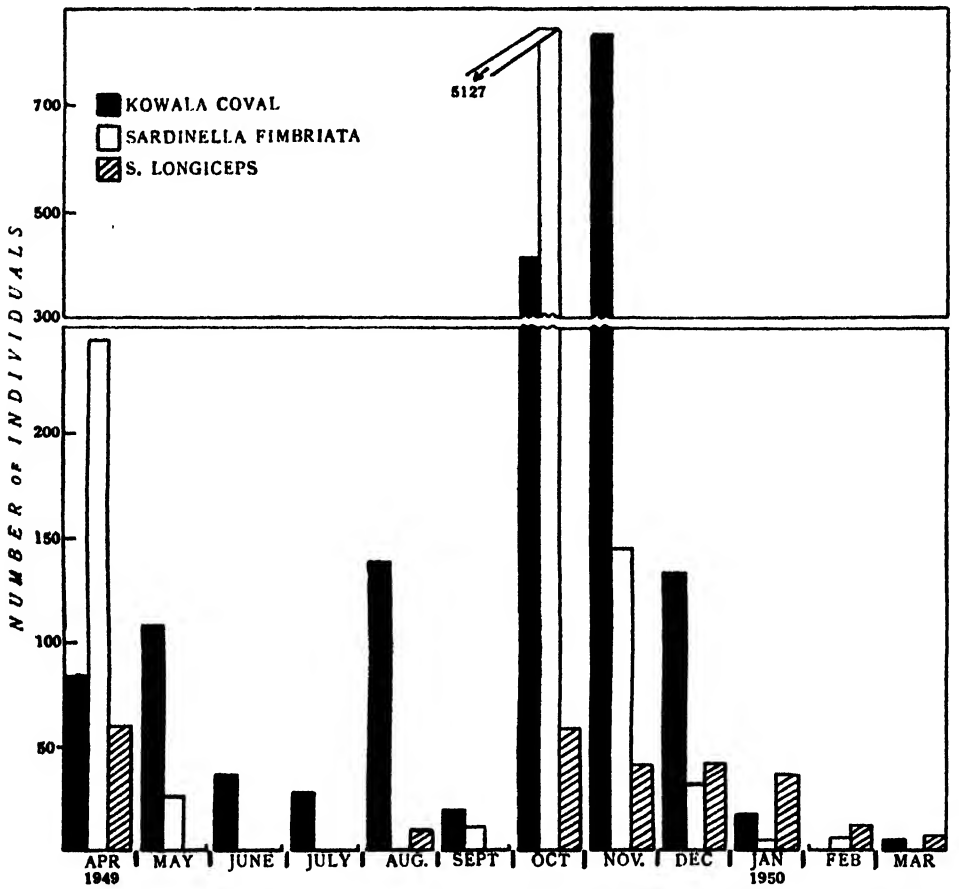

FIG. 1. Variation in abundance of *Kowala coval*, *Sardinella fimbriata* and *Sardinella longiceps*.

were obtained. *Sardinella fimbriata* occurred in April and May and again from September to December and was conspicuously absent during June, July and August with an exception of 3 specimens obtained in the third week of June. During the months of January, February and March, 1950 also, its catches were poor. Though it occupies third rank in the total abundance of all species, the high numerical value of this species is not due to its relative abundance but its chance occurrence of 5,086 specimens obtained on 13th October, 1949. Specimens of size range 9·4 to 17·1 cms. with a modal size range of 12·5 to 14 cms. were obtained in the gill net. The catches of this species in the boat seine were negligible. *Sardinella longiceps*, the oil sardine, commercially a very important fish of this coast, was scarce in the inshore catches. As this fish occurs in shoals the few specimens caught at irregular intervals may be regarded as stragglers into the inshore area. The fishery of the oil sardine beyond the region of the sampling area was fairly good during the year as was observed from the commercial catches. Specimens of size range 11 to 19 cms. with a modal size range of 13 to 15·5 cms. were obtained in the gill net. *Sardinella albella* was insignificant in the collections. Specimens of size range 12–17 cms. with a modal size range of 14 to 15 cms. were obtained.

Fig. 2 indicates the variation in abundance of a few more clupeids, *Opisthopterus tardoore*, *Dussumieria hasselti*, and *Pellona ditchoa*. Of these the

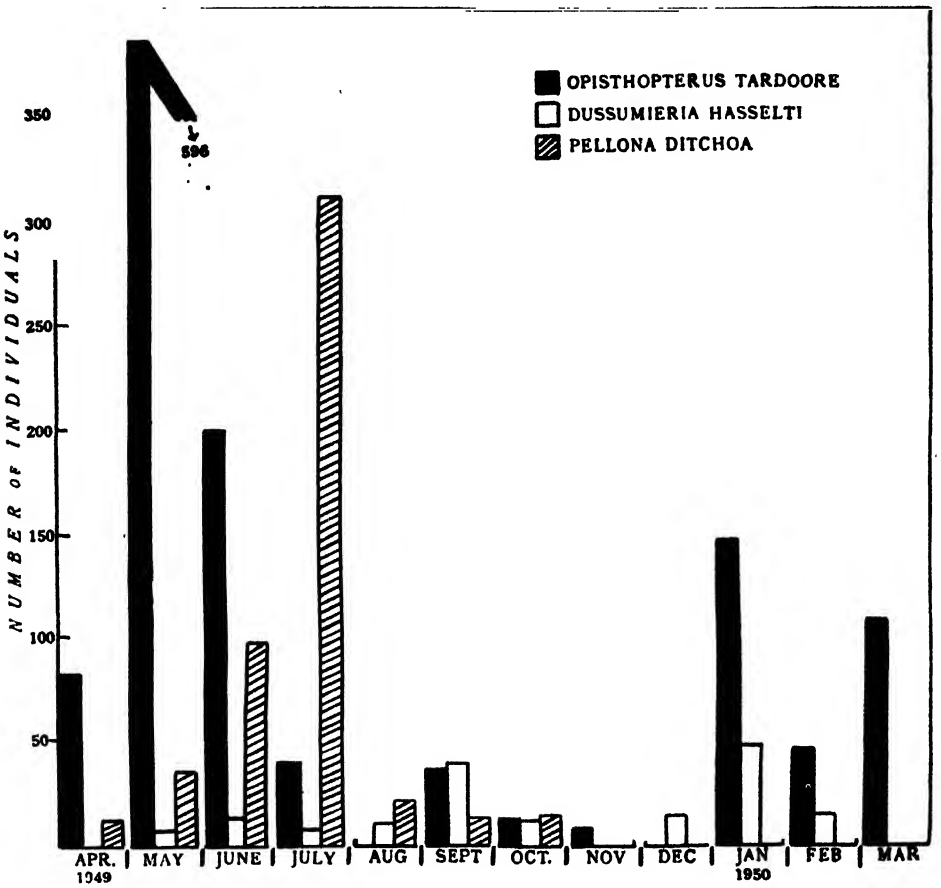

FIG. 2. Variation in abundance of *Opisthopterus tardoore*, *Dussumieria hasselti* and *Pellona ditchoa*.

most conspicuous species was *Opisthopterus tardoore*. This species occurred in fair abundance from April to July, 1949 and again to a smaller degree from January to March, 1950. The modal size of this species in the boat seine catches showed considerable fluctuation. The size range of the specimens caught in the gill net was 8 to 20 cms. and their modal size ranged from 10 to 13 cms. *Pellona ditchoa* occurred in good numbers during June and July. They were scarce in the gill net collections. Specimens of size range 5 to 7·5 cms., excluding the post-larvae, were frequently obtained in the boat seine. *Anodontostoma chacunda* was insignificant in the collections. It occurred in small numbers from April to September, 1949 and again in March, 1950. *Dussumieria hasselti* which occurs in considerable numbers during certain years was represented by very few specimens during the year under consideration.

ENGRAULIDAE.

This family was represented by five species of *Thrissocles* and four species of *Anchoviella*.

Fig. 3 shows the relative abundance of three species of *Thrissocles*, *T. mystax*, *T. malabaricus*, and *T. purava*. Of these the most dominant species

was *T. mystax* which was numerically 88·9 per cent of these anchovies. This species had two periods of dominance, one from April to August, 1949 when they

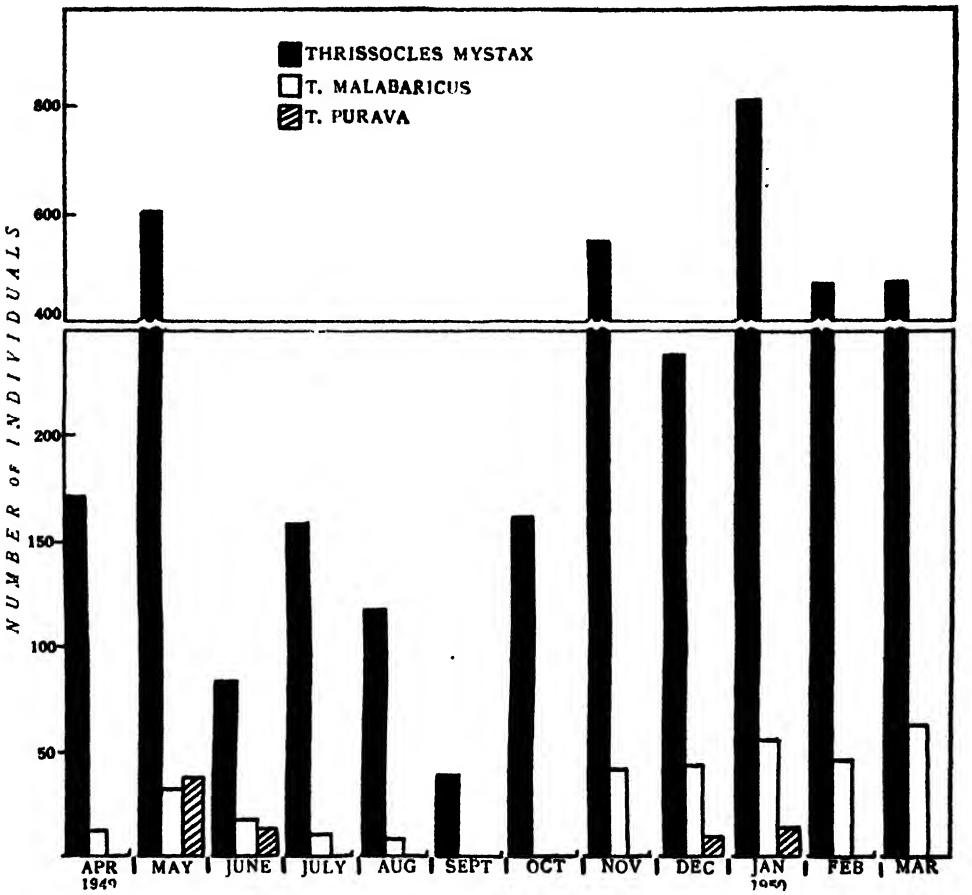

FIG. 3. Variation in abundance of *Thrissocles mystax*, *T. malabaricus* and *T. purava*.

were caught mostly in the boat seine with smaller modal size range 5 to 9·5 cms. excluding the post-larvae and the other from November, 1949 to March, 1950. During the latter period the fishery was both abundant and steady. Mostly large sized specimens with a modal size range 13·5 to 15·5 cms. were caught in the gill net. The catches in the boat seine during this period were insignificant. *T. malabaricus* was caught in limited numbers and followed the same pattern of occurrence as *T. mystax*. The other three species were insignificant. Only 4 specimens of *T. dussumieri* were caught during the year.

Fig. 4 represents variation in the occurrence of three species of *Anchoviella* popularly known as whitebaits. The species *A. tri* and *A. heterolobus* constitute a rich fishery along the Malabar coast during the rainy months from June to October when generally the other major fisheries are poor. *A. tri* was one of the abundant and common fish contributing considerably to the richness of the inshore fishery. It was present all through the year except in March but the peak of abundance was from June to September. The abundant but discontinuous catches particularly during the peak season indicate the behaviour pattern of this species namely the sudden incursion and the equally abrupt excursion of the shoals into and from the inshore area. The mean size ranged from 5·7 to 8·3 cms. excluding the post-larvae and the catches were mostly confined to the boat seine. The fishery of

A. heterolobus was less important compared with that of *A. tri*. It occurred in October, 1949 and again from December, 1949 to February, 1950. Its high numeri-

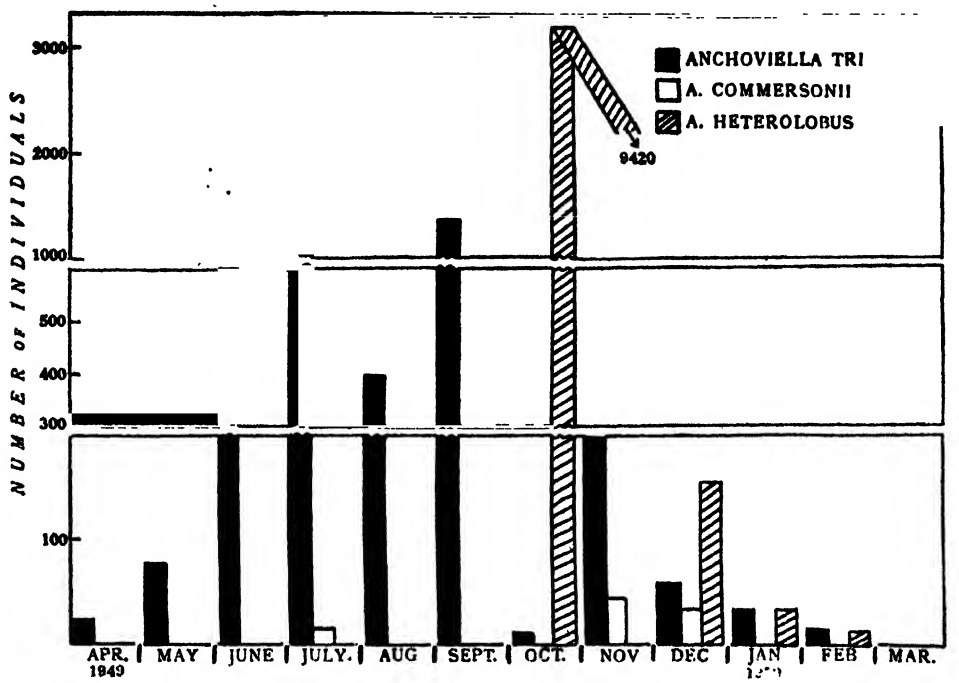

FIG. 4. Variation in abundance of *Anchoviella tri*, *A. commersonii* and *A. heterolobus*.

cal rank was only due to a heavy catch of 9,420 specimens during the last week of October. Specimens of size range 6·2 to 10·1 cms. excluding the post-larvae with a modal size range 7 to 8·5 cms. were obtained. *A. commersonii* was caught in limited numbers during November-December. Only 5 specimens of *A. indica* were caught during the first week of September.

LACTARIDAE.

Lactarius lactarius popularly known as big-jawed jumper occurred intermittently throughout the year in small numbers. It was dominant in the catches during June and July (Fig. 5). The size range of the specimens in the gill net was 8·5 to 18 cms. with a modal size range of 11 to 14 cms. whereas the size range of those caught in the boat seine was 5 to 12 cms. excluding the post-larvae with a modal size range 6 to 9·5 cms. Except that it occurs in small numbers along with other species of fish *Lactarius lactarius* does not form a fishery as such along the Malabar Coast. But further south along the west coast in Travancore this species contributes to a rich fishery with larger sized fish.

CARANGIDAE

Eight species of this family were recorded during the year of which two species—*Caranx kalla* and *C. djedaba* occurred at frequent intervals.

The variation in abundance of *C. kalla* and *C. djedaba* is shown in fig. 5. *Caranx kalla* occurred from April to July and again from the end of September, 1949 to March, 1950. The size of the specimens ranged from 8 to 13 cms. with a

modal range of 9 to 11 cms. They were caught mostly in the gill net. *C. djedaba* was a minor fish in the inshore area and occurred in April and May, 1949 and from

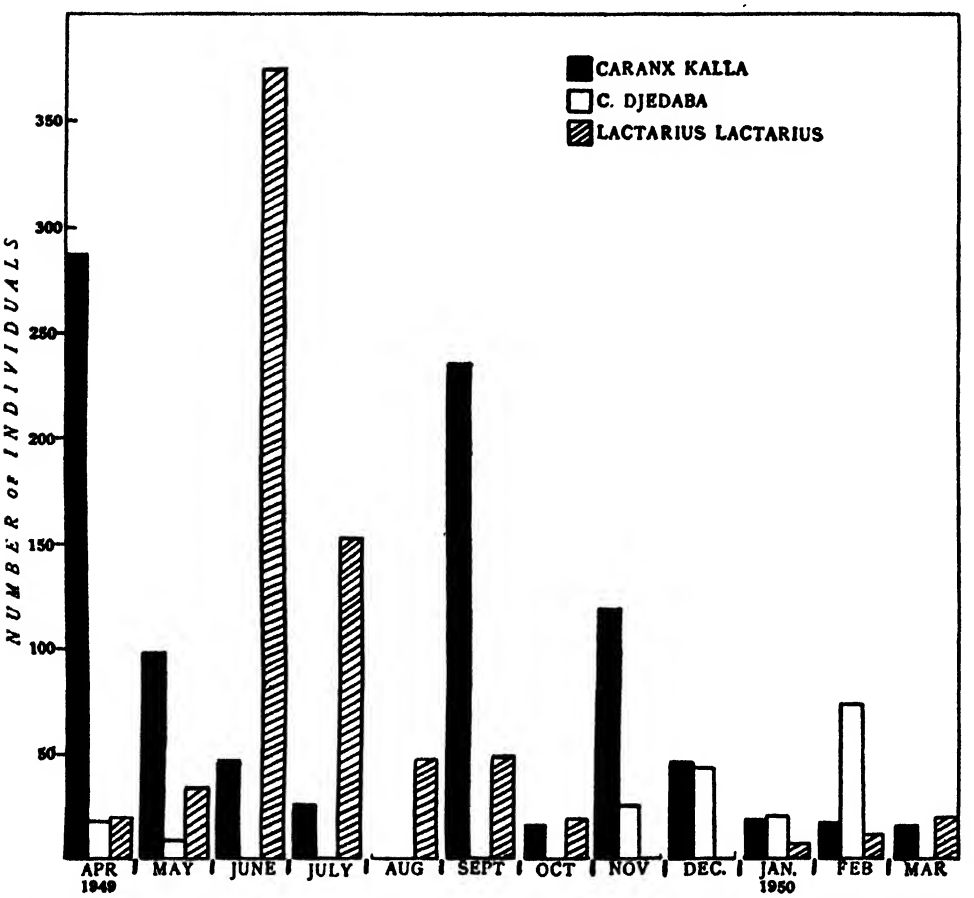

FIG. 5. Variation in abundance of *Caranx kalla*, *C. djedaba* and *Lactarius lactarius*.

November, 1949 to March, 1950, with a size range 7 to 14·5 cms. and a modal size range 8 to 10 cms.

LEIOGNATHIDAE

This family was represented by six species of *Leiognathus*, *L. splendens*, *L. insidiator*, *L. blochi*, *L. ruconius*, *L. equulus* and *L. bindus*, popularly known as silver bellies, and *Gazza minuta* and *Gerres punctatus*. Of these *L. splendens*, was the dominant species, while fair numbers of *L. insidiator*, *L. blochi* and *L. ruconius* were also obtained. All these species considered as a whole appeared abundantly and more or less steadily from June to October, 1949 (Fig. 6). From the trend of the commercial fisheries at Calicut it was observed that the silver bellies formed a dominant fishery during the same period. The regression in abundance during the latter half of August is attributed to the occurrence of 'red water' in the area during the period.

Leiognathus splendens ranked first among the silver bellies (Fig. 6). This species was seasonal in occurrence being abundant from the last week of June to the middle of September. The size ranged from 5 to 11·5 cms. excluding the post-larvae, with a modal size range 6·5 to 8 cms. *L. insidiator* occurred in fair numbers

during September and October. *L. blochi* was also collected in fair numbers in June and again in September and October. Though the fishery of *L. ruconius*

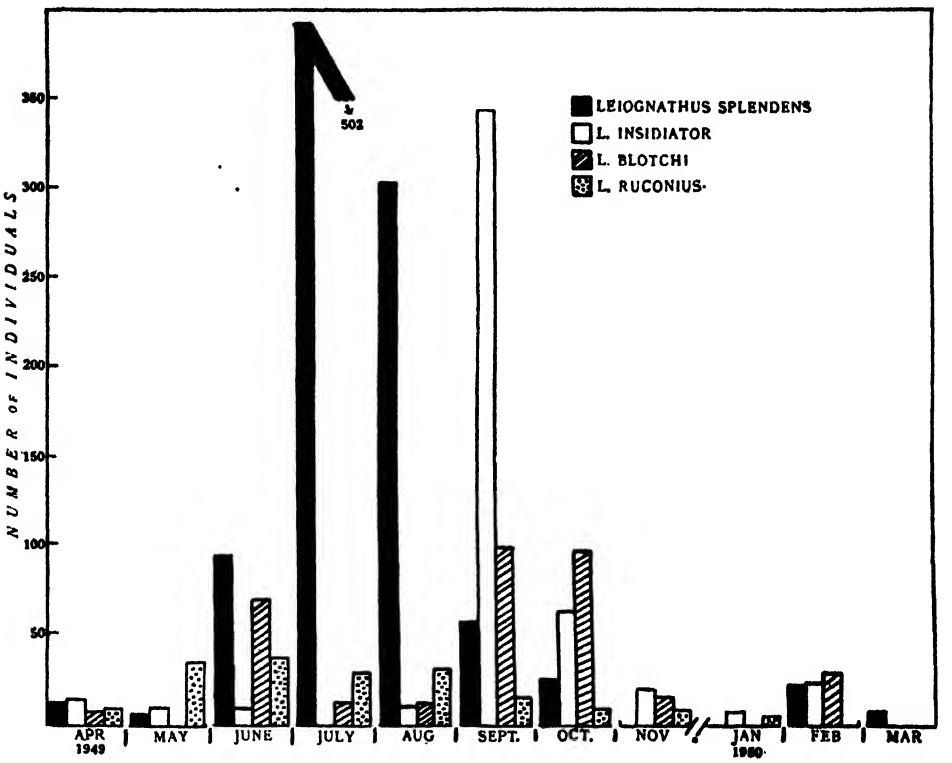

FIG. 6. Variation in abundance of *Leiognathus splendens*, *L. insidiator*, *L. blochi* and *L. ruconius*.

NOTE.—The authors regret that *L. Blochi* is wrongly spelt in the figure.

and *L. bindus* have been noticed to be rich in certain years they occupied a low rank during the year under consideration. As is usual with the fishery of silver bellies it was poor during April-May and from November, 1949 to March, 1950.

SCIAENIDAE.

Family Sciaenidae was represented by *Pseudosciaena sina*, *Johnius belengeri*, *Otolithes ruber*, *O. argenteus* and doubtful species of *Pseudosciaena*. The pattern of occurrence of the members of this family is very different from that of other groups of fishes. The Sciaenids are particularly dominant from January to July when other fisheries are generally poor. They are very poorly represented from August to December. They were caught mostly in the boat seine.

Pseudosciaena sina occurred in good numbers during April and May, 1949 and again in fairly large numbers in March, 1950. (Fig. 7). The trend of occurrence of *Johnius belengeri* was the same as that of *P. sina*. They were similar in sizes also. The size ranged from 5 to 17 cms. excluding the post-larvae. *Otolithes ruber* was dominant in the catches from April to August, 1949 and again in March, 1950. The size ranged from 5 to 21 cms. excluding the post-larvae. Except for two weeks, one in April and another in October, when *O. argenteus* was collected in fair numbers this species was insignificant during the rest of the year.

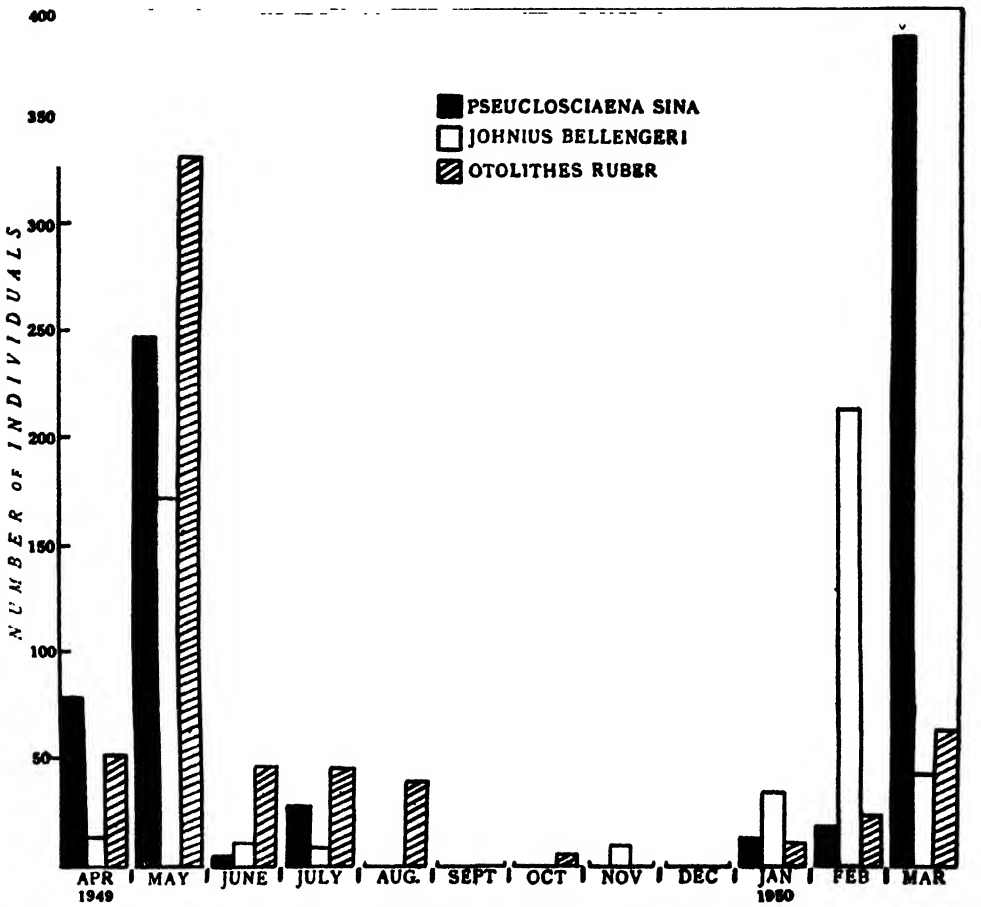

FIG. 7. Variation in abundance of *Pseudosciaena sina, Johnius belengeri* and *Otolithes ruber*. (NOTE.—The authors regret that *Pseudosciaena sina* and *Johnius belengeri* are wrongly spelt in the figure.)

SOLEIDAE.

Solea ovata indicated a very restricted occurrence. (Fig. 8.) It appeared in the catches in appreciable numbers in August and again in the second week of October. The size of the specimens ranged from 6 to 8·7 cms.

CYNOGLOSSIDAE.

This family was represented by *Cynoglossus semifasciatus*, *C. dubius* and *C. puncticeps* of which *C. semifasciatus* contributed to a rich fishery in the inshore area and appeared in large numbers while the other two species were practically insignificant in the catches.

The variation in abundance of *Cynoglossus semifasciatus* is shown in fig. 8. This species, which is popularly known as the Malabar sole was the most persistent and abundant fish of the inshore area constituting 21 per cent of the total fish catch for the year. It was caught mostly in the boat seine. The Malabar sole appeared in fair numbers in April and early part of May after which its number diminished in the catches till October. October recorded very heavy catches of this fish and again there was a regression in its occurrence till January, 1950. From January to March the catches were abundant and steady. The pattern of its occurrence in the departmental catches was similar to that of the commercial fishery of the Malabar sole along this coast. From January to March there was practically a

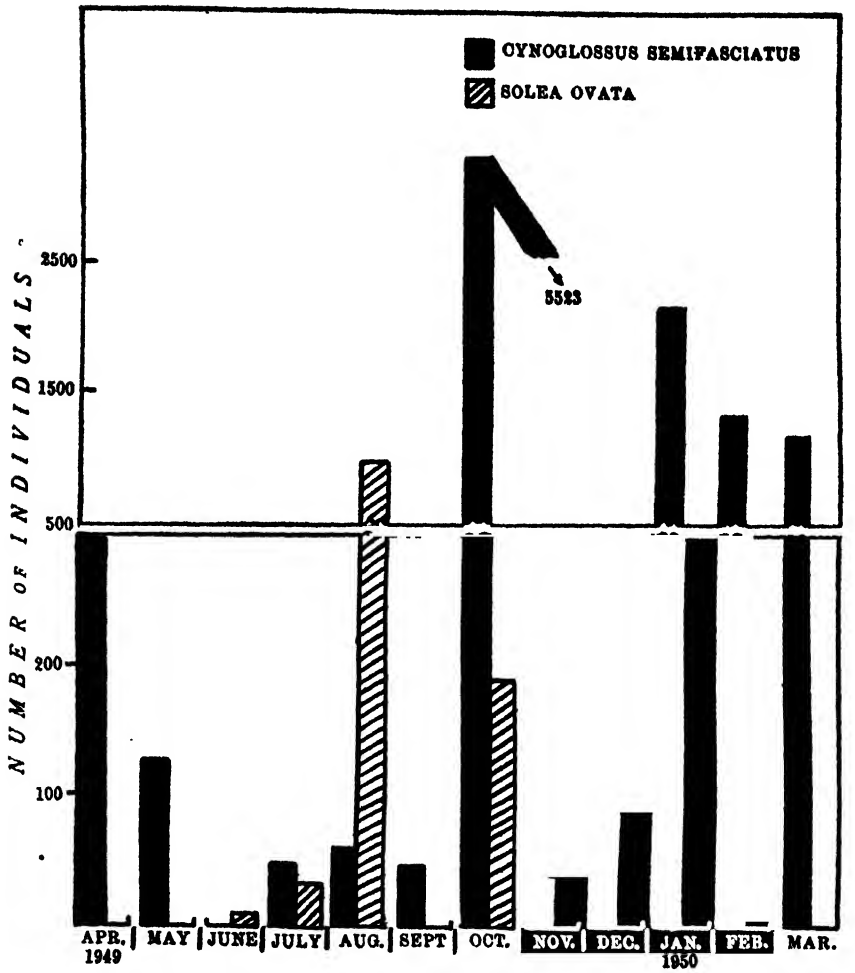

FIG. 8. Variation in abundance of *Cynoglossus semifasciatus* and *Solea ovata*.

continuous recruitment of juvenile forms of this species into the inshore fishery. The size of specimens ranged from 5 to 15 cms. excluding the post-larvae with a modal size range of 7 to 11·5 cms.

CARCHARHINIDAE.

Three species of this family were recorded of which *Scoliodon sorrakowah* was prominent in the collections. 188 specimens of this fish were obtained at wide intervals. But they were represented in the collections continuously from January to March, 1950, in limited numbers. Only juvenile specimens with size range 11 to 30 cms. were generally caught in the inshore area.

ARIIDAE.

Two species of this family *Tachysurus dussumieri* and *Osteogeneiosus militaris* were recorded, of which the latter was more abundant during the year. A total of 443 specimens was obtained mostly in the boat seine. The size ranges for *Tachysurus dussumieri* were 5 to 10·9 cms. and those for *O. militaris* were generally from 5 to 11·5 cms.

Mugilidae

Two species of Mugilidae, *Mugil longimanus* and *M. speigleri* were recorded, of which the latter was more abundant. The total number of mullets obtained in the catches was relatively poor. The sizes generally ranged from 13 to 16 cms.

Polynemidae

Three species of this family were present in the collections of which *Polydactylus heptadactylus* was the most common. The fish was obtained frequently in the inshore collections the total number caught being 529. It showed a discontinuous distribution and was more abundant in the boat-seine hauls. The size ranges of the specimens were from 5 to 10·5 cms. in the boat seine samples excluding the post-larvae.

Centropomidae

This family was represented by a single species, viz. *Ambassis gymnocephalus*. It is a very common perch of this region and was present in 45 out of 52 weeks. This small fish, though unimportant as a food fish, richly supported the inshore fishery throughout the year. It was caught mostly in the boat seine. The modal size fluctuated from 5 to 7·5 cms.

Trichiuridae

This family was represented by *Trichiurus haumela* which is an important fish of this coast. It was present abundantly during September and October, 1949. Specimens of size range from 12 to 52 cms. were obtained in the collections.

Scombridae

This family was poorly represented in the catches. The mackerel, *Rastrelliger kanagurta*, which contributes to a rich fishery along this coast in 8 fathoms area and beyond was very poorly represented in the inshore collections. Only eight specimens were obtained for the entire year.

Cybiidae

This family was represented by two species, *Scomberomorus commerson* and *Scomberomorus guttatus*. They were scarce in the collections, the total number obtained being 31 and 44 respectively. They were all small sized, their maximum length not exceeding 28 cms.

Prawns and Crabs.

TABLE 1.

The weight of prawns in pounds and the number of crabs caught in the fishing nets during different months of the year.

Months.	Apr. 1949	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan. 1950	Feb.	Mar.
Prawns, wt. in pounds ..	21·2	28·0	2·2	4·2	7·0	Nil	·2	·1	·9	37·1	38·0	51·7
Crabs, Nos. ..	171	257	2	14	4	Nil	3	Nil	5	123	112	85

Prawns and crabs formed a considerable part of the catches especially in the boat-seine. Table 1 shows the weight of prawns in pounds and the total number of crabs caught during the twelve months. Both prawns and crabs occurred abundantly for five months, April and May, 1949 and from January through March, 1950. During the other seven months they were practically absent except for stray specimens. The species of prawns caught were *Parapenaeopsis stylifera*, *Metapenaeus dobsoni*, *M. affinis* and *Penaeus indicus* in the order of abundance. It may be mentioned here that good quantities of a small shrimp, *Acetes dispar*, which forms a favourite food of several species of fishes in the inshore area, were caught in the boat seine during the hot months, March, April and May. When this shrimp is caught in large quantities it is utilised as food by the people of this coast.

The species of crabs obtained in the collections were *Neptunus sanguinolentus*, *N. pelagicus* and *Charybdis natator*. Of these *N. sanguinolentus* was the most abundant species.

Animals which have no economic value.

TABLE 2.

The number of other animals caught in the fishing net during the different months of the year.

Months.	Sea anemone.	*Squilla.*	*Cavernularia.*	*Sepia.*	*Loligo.*	Jelly fish.	Ctenophore.
Apr., 1949	242	66	81	33	3	..	..
May ,, ..	..	41	36	20	2	26	..
June ,, ..	..	..	..	..	..	..	..
July ,, ..	..	..	4	..	38	1	..
Aug. ,, ..	..	..	..	..	5	..	..
Sept. ,, ..	..	..	..	..	8	..	..
Oct. ,, ..	..	..	..	..	..	..	..
Nov. ,, ..	..	..	4	..	..	..	..
Dec. ,, ..	..	..	..	..	..	..	Plenty.
Jan., 1950	1	9	15	..	5	3	Plenty.
Feb. ,, ..	1	19	317	..	7	3	..
Mar. ,, ..	..	57	59	41	12	..	..

Other animals such as the sea anemone, *Squilla*, *Cavernularia*, *Sepia*, *Loligo*[1] and a Ctenophore (*Pleurobrachia sp.*) caught in the fishing net have no economic value. They were mostly caught in the boat seine and occurred in fair numbers, as shown in Table 2 during the months, April and May of 1949 and January, February and March of 1950. Except for *Loligo*, they are practically absent during the other months. The occurrence of large numbers of sea anemones in the inshore area during April, 1949 is interesting. They must have been uprooted from their habitat elsewhere and come to the inshore area along the currents. During December and January a large number of ctenophores were caught in the boat seine. These elements seem to dominate in the inshore area during the months when prawns and crabs are caught abundantly. The only two uneconomical fish caught occasionally were the species of *Triacanthus* and *Tetraodon*.

Post-larvae and immature fishes.

Post-larvae of several species of fishes occurred in the boat seine collections in considerable numbers during April, May, June and December of 1949 and

[1] *Loligo* which is utilised elsewhere, is not generally used as food along the Malabar Coast.

January, February and March, 1950 and the peak month of their occurrence was March. Those caught in appreciable numbers were the post-larvae of *Kowala coval*, *Pellona ditchoa*, *Opisthopterus tardoore*, *Anchoviella tri*, *Thrissocles mystax*, *Polynemus spp.*, *Ambassis gymnocephalus*, *Lactarius lactarius*, *Pomadasys hasta*, *Chorinemus tala*, *Leiognathus blochi*, *L. insidiator*, *L. ruconius*, *L. splendens*, *Pseudosciaena sina*, *Johnius belengeri*, *Otolithes ruber*, *Cynoglossus semifasciatus* and *Solea ovata*. There was considerable variation in the numbers of the post-larvae of these fishes and the period over which they occurred in the inshore area. Amongst the forms mentioned above, *Opisthopterus tardoore*, *Thrissocles mystax*, *Leiognathus splendens* and *Ambassis gymnocephalus* appeared in abundance during the peak season. Some species like *Megalops cyprinoides*, *Mene maculata*, *Scatophagus argus*, *Epihippus orbis*, *Epinopholus diacanthus*, *Lutjanus argentimaculatus* and *Lutjanus marginatus*, were caught only in the post-larval stage and the later stages of these species did not occur in the inshore area. It is significant that the post-larval stages of the mackerel, *Rastrelliger kanagurta* and the oil sardine, *Sardinella longiceps*, the two commercially important fishes of this coast, were completely absent in the departmental catches.

Species like *Scoliodon sorrakowah*, *S. palasorrah*, *S. walbeehmi*, *Scomberomorus guttatus*, *Tachysurus dussumieri*, *Chorinemus tala* and *Parastromateus niger* which form rich fisheries beyond the 6 fathom area along this coast, occurred in the inshore region only in their juvenile stages.

Some Aspects of Physical and Biological Environment.

Physical environment.

Fig. 9 shows the monthly average salinity and temperature readings for the year. The range in salinity was from 26·4‰ to 36·1‰. During the summer months of April and May the salinity reading was high. There was a sharp fall in salinity with the commencement of the South-West monsoon in June. From July to October it indicated an upward trend after which it was more or less steady till the end of the period ranging from 33·35‰ to 35·66‰.

During April and May the average water temperature was 30·02°C. There was a lowering of the temperature after the commencement of the monsoon and it continued to be low during July, August and September with an average of 26·49°C. The temperature rose up to 28·87°C. in November and there was again a slight fall in December and January after which there was an upward trend showing a reading of 28·66°C. in February and 30·20°C. in March.

There seems to be a definite relationship between the salinity values and the extent of fish catches. During June, July and August salinity not only showed a lower value but fluctuated considerably from week to week. During this period the fish catches were also poor. The fish catches improved considerably in the months of September and October when it is seen that there is a rise in the salinity reading. With the steadiness in higher salinity value from the middle of November there is a correspondingly uniform good fish catches.

There does not seem to be any perceptible relationship between the temperature readings and the fish catches. Perhaps when data on these are available for a few years it may be possible to find out if temperature has any relation to the behaviour of the fish populations. Both salinity and temperature readings do not give any indication as to why there was lesser number of species of fishes during the months of October, November and December (vide Table 3).

Rainfall.—The total rainfall at Calicut for the different months is shown in fig. 9. The heavy rainfall along the West Coast is one of the factors which affect the physico-chemical condition of the coastal waters. The total rainfall at Calicut during the year under consideration was 129·19 inches and it was spread

over 33 weeks. Unusually there were a few good rains during April, 1949. The heaviest rainfall in the year was during the months of May, June and July.

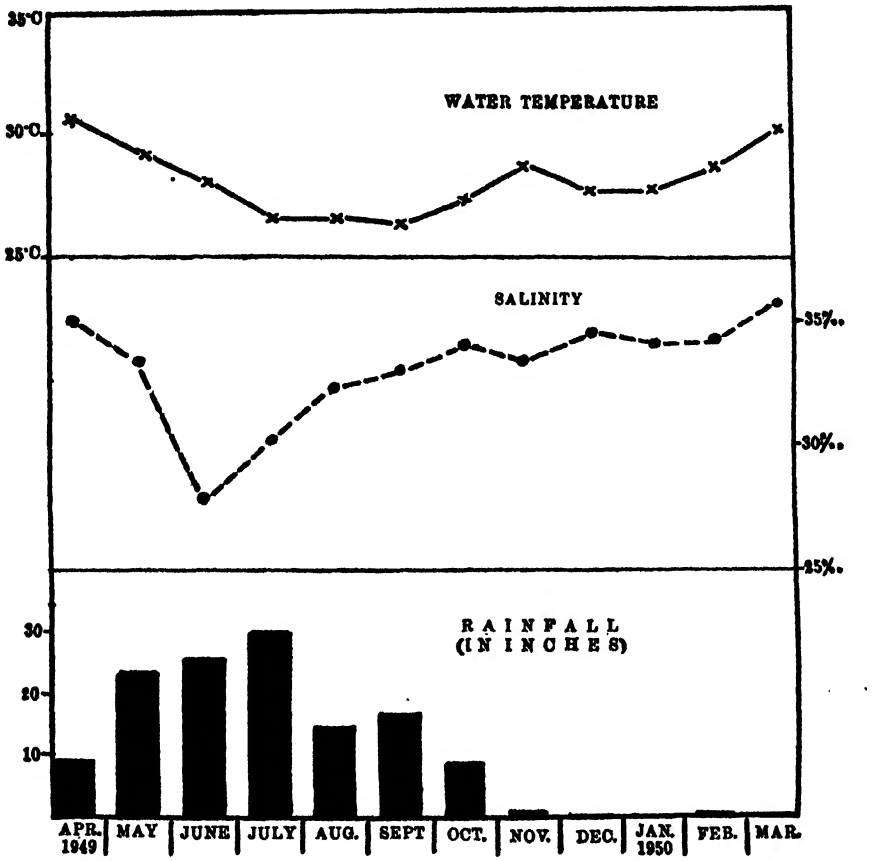

FIG. 9. Average monthly water temperature and salinity and monthly total rainfall.

Turbidity and light conditions.—From the records maintained on the weather condition such as the sky being cloudy, foggy, clear, etc., there does not seem to be any relationship between variations in these factors and the fish catches. The water was slightly turbid, turbid or very turbid during 37 weeks and it was clear or very clear on 14 weeks of the year. For two weeks in June at the period of commencement of the South-West monsoon the bottom clay had been stirred up resulting in the extreme turbidity of water, almost to the extent of forming a slush, when, the fish catches were very low. The condition of water from November to March was either slightly turbid or turbid and the fish catches during these months were uniformly good. The fish catches were normally low on days when the water was clear.

Currents.—It has not been possible to correlate the fish catches with the currents as there is no precise knowledge of sea currents along this coast. The nature of the tidal currents has, however, been noted for different dates. The rising tidal current is roughly from north to south and the falling tidal current is from South to North. The rising tides have generally shown a tendency towards higher catches when other adverse factors have not intervened.

Biological environment.

The quantity of edible plankton available in the inshore waters was moderate during April and May though appreciably better in the latter month. There was a marked decline in the zooplankton during the monsoon months. From the end of July to the end of December edible planktonic elements such as copepods, cladocerans, larval and adult pelagic polychaetes and larval bivalves occurred in large numbers except during about three weeks in August when there was a swarm of *Noctiluca*. From January to April the plankton was dominated by non-food elements such as medusae, chaetognaths and combjellies.

During the monsoon months the inshore sea bottom was practically devoid of animals, only occasional members of a few forms such as *Cavernularia sp.*, *Lucina vesicula*, *Theora opalina* and a nemertine species occurring now and then. From September onwards there was a rapid colonisation of the mud bottom, chiefly by polychaetes and a phoronid species. The dominant member among these was *Prionospio pinnata* a polychaete of very high fish-food value. By November the bottom fauna had grown very rich and continued to be rich till April though there was a gradual decline in numbers.

While the fishery was poor during the monsoon months it recovered considerably from September onwards. The poverty of the monsoon fishery is correlated among other factors with the absence of fish food in the area. During the time of recovery of the fishery there was rich planktonic food available and the bottom fauna was also developing. During August and September, however, there was a depression in the fishery for some weeks and this was correlated with the abundance of *Noctiluca* and on some occasions with large swarms of *Nitzschia sigma* and a species of Chloromonadineae. Again there were good catches of fishes during October and November and the plankton food was also rich during this period. Recovery of the demersal fish *Cynoglossus semifasciatus* occurred from January onwards and this change could be correlated with the growth of polychaete and other soft bodied bottom animals in the area during that period.

General Observations.

A few general observations made during the course of this investigation are given below. Any conclusion drawn from these is tentative and will have to be confirmed by further study on the subject.

Sampling method.—Considerable difficulty was experienced in devising a suitable method for sampling the fish population for this study. If the population study was confined to a single species of fish it would have been comparatively easy to devise a sampling method as a gear best suited for the particular species could have been used. But to sample all the species in the area with varied sizes and habits was found to be very difficult. Different types of nets used along this coast were experimented in this connection and it was observed that each type of net proved to be selective both in respect of species of fishes and also the different sizes of one and the same species of fish. After a number of experimental trials, two nets, a boat seine and a gill net, were selected for taking out the fishes. While each of these nets was observed to be selective in certain respects, each proved to be complementary to the other; and the collections made by these nets together provided to be a reliable approximation of the condition of the population in the sea. Every precaution was taken to avoid any working error in the operation of the nets. The boat seine collected mostly the small sized species, bottom species, species with sluggish habit, smaller sizes and post-larval stages of shoaling species, prawns and others while the gill net caught mostly the large sized shoaling fishes.

To illustrate the selective nature of the two nets, the total number of ten species of fishes caught during the year with the two nets is given below.

No.	Species.	Number caught in Gill net.	Number caught in Boat seine.
1	*Sardinella fimbriata*	5,553	45
2	*S. longiceps*	258	9
3	*Kowala coval*	1,760	53
4	*Caranx kalla*	909	15
5	*Leiognathus blochi*	325	20
6	*Anchoviella heterolobus*	6	9,616
7	*A. tri*	16	5,068
8	*Cynoglossus semifasciatus*	700	10,132
9	*Ambassis gymnocephalus*	156	1,334
10	*Polydactylus heptadactylus*	38	491

The first five species were caught mostly in the gill net while the last five mostly in the boat seine. It is obvious from this that the use of only one net would have given an erroneous picture of the population in the sea.

Further, the size composition of the same species differs in the two nets as could be seen from below :

Period.	Species.	Gill net catch.			Boat seine catch.		
		No. of specimens.	Size range.	Mean size.	No. of specimens.	Size range.	Mean size.
Fourth week of June, 1949 ..	*Lactarius lactarius.*	89	86–183 mm.	126·43 ± ·23 mm.	251	54–105 mm.	75·66 ± ·65 mm.
Second week of March, 1950	*Thrissocles mystax.*	73	64–185 mm.	152·38 ± ·10 mm.	25	51–70 mm.	56·56 ± ·12 mm.

From the above it is clear that at the same period different sizes of the same species were caught in the two nets. This was generally true of several other species also. Mean size and standard deviation calculated for any species would therefore be applicable only to the fish caught in any particular net and not to its population in the sea. It is for this reason that a detailed discussion on the size frequency factor of the various species of fishes has not been attempted in this paper.

Major groups.—The fishes collected in the inshore area can broadly be grouped into Clupeoids, Pleuronectids, Leiognathids, Sciaenids and Carangids which together formed 91·6 per cent and the miscellaneous fishes consisting of other species constituted 8·4 per cent of the total number of fish caught. The number of fish included under each group and its percentage in the total number are given below:

	Total number.	Percentage in total number.
Clupeoids	29,142	56·4
Pleuronectids	12,093	23·4
Leiognathids	2,116	4·1
Sciaenids	2,038	3·9
Carangids	1,955	3·8
Miscellaneous	4,356	8·4

The number of weeks during which the different groups occupied the first ranks were—Clupeoids 32, Pleuronectids 10, Miscellaneous species 4, Leiognathids 3, Carangids 2 and Sciaenids 1.

Number of species.—There was a good variety of species occurring in the inshore area throughout the year. Altogether 85 species of fish were caught during the year.

TABLE 3.

Showing the number of species of fishes caught during the 52 weeks and the totals for the 12 months.

Months.	Apr. 1949	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan. 1950	Feb.	Mar.
I week ..	29	29	24	21	27	15	22	4	18	25	32	27
II ,, ..	21	27	11	15	17	24	12	19	20	22	33	30
III ,, ..	26	28	32	30	8	21	15	18	23	23	30	27
IV ,, ..	23	26	37	28	16	26	11	16	23	22	25	25
V ,, ..	..	20	..	..	16	..	..	22	..	35	..	..
Total for the month ..	45	48	45	44	44	42	33	34	32	49	47	44

Table 3 shows the number of species of fish caught during different weeks of the year and also over different months. The lowest number of species caught was 4 in the first week of November and the highest number was 37 in the fourth week of June. From the monthly totals of number of species it is seen that there was a fair uniformity of variety of species over major part of the year. The number of species per month ranged from 42 to 49 except during October, November and December when it was 33, 34 and 32 respectively. The lower number of species during these months appears to be due to the very poor catches in the boat seine which usually collects a large variety of species and also to the saturation of the inshore area during the period with a few shoaling fishes in exceptional numbers to the exclusion of other species.

Abundance.—In reckoning the abundance of a species of fish Warfel and Merriman (1944) have made a distinction between its relative and total abundance. Relative abundance of a species is determined by its frequency of occurrence in good numbers. From the fishery point of view a sustained yield of a species in a fishery is more important than its exceptional abundance if the latter is due to an erratic appearance for a short duration. The high rank obtained by *Sardinella fimbriata* and *Anchoviella heterolobus* during the year was due to their appearance in very large numbers (5,086 and 9,416 respectively) just once for each species.

The species which occupied a high rank in respect of relative abundance during the year were *Cynoglossus semifasciatus, Anchoviella tri, Opisthopterus tardoore, Kowala coval, Ambassis gymnocephalus, Thrissocles mystax, Caranx kalla, Leiognathus splendens* and prawns and crabs. The relative abundance of various species of fishes can be seen in figures from 1 to 8 and also in Appendix 2.

Distribution.—The only permanent resident of the inshore area was *Ambassis gymnocephalus* which was caught practically throughout the year. Further this was the only species which was observed to spawn in the inshore area. All other species were migrants to this area and the period of their stay differed for different species. *Cynoglossus semifasciatus* and *Thrissocles mystax* indicated prolonged stay for nearly 6 to 8 months. Species of *Anchoviella, Sardinella* and *Leiognathus* were just transient residents in the area with abrupt incursions into and excursions from this area. The only demersal fish of the area was *Cynoglossus semifasciatus* and most of the other fish may be regarded as 'pelagic' species moving about in

schools or sometimes in large shoals. Individuals of shoals of species of *Anchoviella*, *Sardinella*, *Thrissocles*, *Leiognathus* and others after entry into the inshore area were sometimes observed to get scattered. From the trend of occurrence of the species and their numbers from week to week it was observed that the inshore fishery was characterised by a constantly shifting population. The recruitment of the post-larvae and juvenile stages of several species of fishes into the inshore area from January to May was considerable. The inshore area during this period formed a 'nursery' for the young fish.

From an examination of the gonad conditions of the various species during different seasons of the year it is observed that while most of the species occurring in this area attain maturity in this biotope, they migrate just before spawning perhaps to the offshore area. Fishes with gonads beyond maturity stage IV have rarely been met with except in the case of *Cynoglossus semifasciatus* in which stages V and VII have also been observed. This is corroborated by comparative scarcity of fish eggs in this area.

Seasonal Fluctuations.—There was considerable fluctuation in the extent and the nature of the inshore fishery during different periods of the year.

Fig. 10 indicates monthly fluctuations in the total weight of fish catches in the two nets, the boat seine and the gill net. It shows two regressions in the fishery,

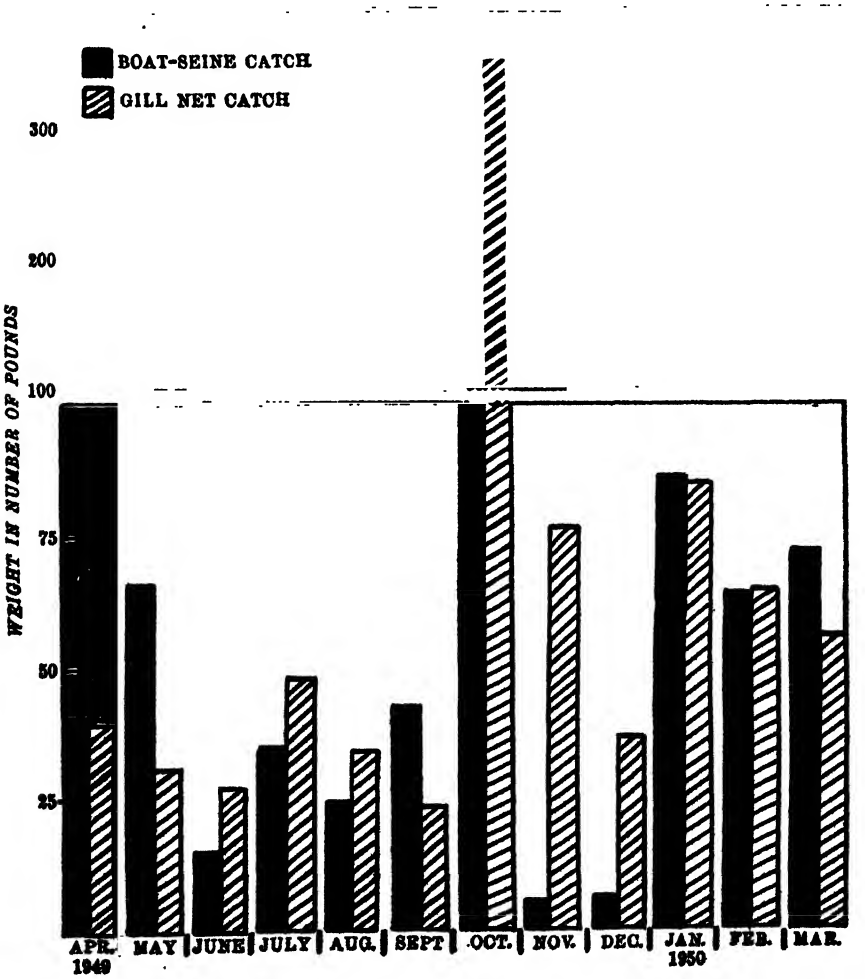

FIG. 10. Variation in the total weights of fish catches obtained in the two nets, the boat seine and the gill net.

one in the month of June and another in August-September. The poor catch in June was due to the extreme turbidity of water caused by the stirring up of the bottom mud at the commencement of the South-West monsoon bringing about a physical intolerance to the fishes in the area and the comparatively low catches in August-September was attributed to the occurrence of 'red water' caused by the abundance of *Noctiluca* and also the blooming of certain phytoplankton forms like *Nitzschia sigma var. indica*, *Oscillatoria erythraea*, *O. thebauti* and a species of Chloromonadinae in the area. The low catches in the boat seine in November and December were due to the absence in the area during the period of species of fish, prawns and crabs caught in that net. The fishery was uniformly good in April and May of 1949 and again from January to March, 1950. Fishes were caught throughout the year although there was fluctuation in their numbers from week to week. In temperate countries, on the other hand, the fish population is practically absent in the foreshore area during the winter months, from December to February, when the water temperature goes down to sub-zero level (Warfel and Merriman, 1944).

It has been observed that the majority of fishes have fairly well-marked seasons of occurrence. The seasons of occurrence of various species and the succession of their fisheries in the inshore area during the year followed, more or less, the same trend as in other years.

Nature of the Inshore Fishery.—As a result of this study it has been possible to assess, to some extent, the fishery value of the inshore area. The principal species contributing to the bulk of the inshore fishery are the Malabar sole, the Whitebait, Silver bellies, Anchovies, the white sardine and prawns and crabs. All the other species constitute the miscellaneous fishery in this area. It is significant that the most important commercial species of this coast, the mackerel, *Rastrelliger kanagurta* and the oil sardine, *Sardinella longiceps* did not occur in the area studied except as stragglers. Thick shoals of these appeared in the commercial fishing grounds beyond the 6 fathom line. Large populations of these two species are well known to come close to the coast in the northern portion of South Kanara and North Kanara districts. Similarly certain other species like *Tachysurus dussumieri*, *Parastromateus niger*, *Caranx kurra* and *Scomberomorus guttatus* which form the bulk of the commercial catches during certain seasons did not occur in the inshore waters except in immature sizes.

At present the inshore fishery is not being sufficiently exploited as the fishermen generally prefer to fish in the 8 to 10 fathom area for mackerels, sardines and other species. It is only when these more lucrative fisheries are not being operated or when there are occasional thick concentrations of sole, silver bellies, whitebait or prawns close to the shore, that they fish in the inshore area. There is, however, a good scope for a more intensive exploitation of the inshore fishery.

Summary.

The study on the fish populations of the Malabar Coast is based on the analyses of the weekly fish catches taken in the inshore area near Calicut for a year from April, 1949 to March, 1950. The method used for sampling the fish populations is described. A brief accout is given of the main groups of fishes occurring in the area, indicating the species, their size ranges and seasonal fluctuations and also of the prawns and crabs caught in the fishing nets. There is a chapter on the physical and biological environment in the inshore area and their probable relation to the fluctuations in the fisheries.

Eighty-five species of fishes were recorded during the year. The major species supporting the inshore fishery were *Thrissocles mystax*, *Anchoviella tri*, *A. heterolobus*, *Kowala coval*, *Sardinella fimbriata*, *Opisthopterus tardoore*, *Pellona ditchoa*, *Polydactylus heptadactylus*, *Ambassis gymnocephalus*, *Caranx kalla*, species of *Leiognathus*, *Otolithes ruber*, *Pseudosciaena sina*, *Johnius belengeri*, *Cynoglossus semifasciatus*, and also to some extent the smaller sizes of *Scoliodon sorrakowah*, *Tachysurus dussumieri*, *Lactarius lactarius*, *Trichiurus haumela*, and *Scomberomnoru guttatus*.

Remarks are offered in the paper on the sampling method, distribution and abundance of various species of fishes and the nature of the inshore fishery.

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Appendix 1.

**List of Fishes obtained in the departmental collections in the inshore area off West Hill.*

Class ELASMOBRANCHII
Sub-Class SELACHII
Order LAMNIFORMES
Sub-Order LAMNOIDEI
Family Orectolobidae
Chiloscyllium griseum Mull. & Henle.
Sub-Order SCYLIORHINOIDEI
Family Carcharhinidae
Scoliodon sorrakowah (Cuvier)
Scoliodon palasorrah (Cuvier)
Scoliodon walbeehmi Bleeker
Family Sphyrnidae
Sphyrna blochii (Cuvier)
Order RAJIFORMES
Family Trygonidae
Dasyatis (*Pastinachus*) *sephen* (Forsk.)
Order TORPEDINIFORMES
Family Torpedinidae
Narke dipterygia (Schn.)

Class TELEOSTOMI
Sub-Class ACTINOPTERYGII
Order CLUPEIFORMES
Sub-Order CLUPEOIDEI
Family Clupeidae
Dussumieria hasselti Bleeker
Sardinella albella (C. & V.)
Sardinella fimbriata (C. & V.)
Sardinella longiceps C. & V.
Hilsa kanagurta (Bleeker)
Kowala coval (C.)
Pellona ditchoa C. & V.
Opisthopterus tardoore (C.)
Anodontostoma chacunda (Ham.)

* The classification of fishes is after Berg.

Family Engraulidae
Coilia dussumieri C. & V.
Anchoviella commersonii (Lac.)
Anchoviella heterolobus (Rupp.)
Anchoviella indica (v. Hass.)
Anchoviella tri (Bleeker)
Thrissocles dussumieri (C. & V.)
Thrissocles malabaricus (Bleeker)
Thrissocles mystax (Schn.)
Thrissocles purava (Ham.)
Thrissocles setirostris (Brouss.)

Sub-Order CHIROCENTROIDEI
Family Chirocentridae
Chirocentrus dorab (Forsk.)

Order SCOPELIFORMES
Family Synodidae
Saurida tumbil (Bl.)

Order CYPRINIFORMES
Sub-Order SILUROIDEI
Family Ariidae
Tachysurus dussumieri (C. & V.)
Osteogeneiosus militaris (L.)
Family Bagridae
Mystus gulio (Ham.)

Order ANGUILLIFORMES
Sub-Order ANGUILLOIDEI
Family Muraenesocidae
Muraenesox sp.

Order GADIFORMES
Sub-Order GADOIDEI
Family Bregmacerotidae
Bregmaceros macclellandi Thompson

Order MUGILIFORMES
Sub-Order SPHYRAENOIDEI
Family Sphyraenidae
Sphyraena obtusata C. & V.
Sub-Order MUGILOIDEI
Family Mugilidae
Mugil longimanus Gunther
Mugil speigleri Bleeker

Order POLYNEMIFORMES
Family Polynemidae
Polydactylus plebeius (Brouss.)
Polydactylus heptadactylus (C.)
Eleutheronema tetradactylum (Shaw)

Order PERCIFORMES
Sub-Order PERCOIDEI
Family Centropomidae
Ambassis gymnocephalus (Lac.)
Family Theraponidae
Therapon jarbua (Forskal)
Therapon puta C. & V.
Family Sillaginidae
Sillago sihama (Forsk.)
Family Lactariidae
Lactarius lactarius (Bl. Schn.)
Family Carangidae
Caranx (Selar) djedaba (Forsk.)
Caranx (Selar) kalla C. & V.
Caranx (Carangoides) malabaricus (Bl. Schn.)
Caranx (Caranx) sexfasciatus Q. G.
Megalaspis cordyla (L.)
Decapterus russelli (Rupp.)
Chorinemus tala (C. & V.)
Psenes indicus (Day)
Family Nemipteridae
Nemipterus japonicus (Bl.)
Family Leiognathidae
Leiognathus bindus (C. & V.)
Leiognathus insidiator (Bl.)
Leiognathus ruconius (H. B.)
Leiognathus equulus (Forsk.)
Leiognathus splendens (Cuv.)
Leiognathus blochi (C. & V.)
Gazza minuta (Bl.)
Gerres punctatus C. & V.
Family Pomadasyidae
Pomadasys hasta (Bl.)
Family Sciaenidae
Otolithes ruber (Bl. Schn.)
Otolithes argenteus (C. & V.)
Pseudosciaena sina (C. & V.)
Pseudosciaena sp.
Johnius belengeri (C. & V.)
Family Drepanidae
Drepane punctata (L.)
Sub-Order ACANTHUROIDEI
Family Acanthuridae
Teuthis oramin Gunth.
Sub-Order TRICHIUROIDEI
Family Trichiuridae
Thichiurus haumela (Forsk.)
Sub-Order SCOMBROIDEI
Family Scombridae
Rastrelliger kanagurta (Russell)
Family Cybiidae
Scomberomorus commerson (Lac.)
Scomberomorus guttatus (Schn.)
Sub-Order STROMATEOIDEI
Family Stromateidae
Parastromateus niger (Bl.)
Chondroplates chinensis (Euphr.)
Sub-Order GOBIOIDEI
Family Gobiidae
Gobius sp.
Trypauchen vagina (Bl. Schn.)

Order PLEURONECTIFORMES
Sub-Order PLEURONECTOIDEI
Family Soleidae
Solea ovata Rich.
Brachirus albomaculatus (Kaup.)

Family Cynoglossidae
Cynoglossus dubius Day
Cynoglossus puncticeps (Rich.)
Cynoglossus semifasciatus Day

Order TETRODONTIFORMES
Sub-Order BALISTOIDEI
Family Triacanthidae
Triacanthus brevirostris Temm. & Schl.

Sub-Order TETRODONTOIDEI
Family Tetrodontidae
Tetraodon (*Chelonodon*) *patoca* Ham.

Order BATRACHOIDIFORMES
Family Batrachoididae
Batrachus grunniens (Bloch.)

Appendix 2.

Table showing the number of each species of fish caught in the boat seine and the gill net during different months of the year.

Numbers without the brackets indicate the number of specimens caught in the boat-seine.

Numbers within the brackets indicate the number of specimens caught in the gill net.

Species.	Apr. 1949	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1950	Feb.	Mar.	Totals	Total
Dussumieria hasselti ..	..	5	13	1	11	32	..	..	1	27	5	..	95	168
	..	(2)	..	(7)	..	(7)	(11)	(2)	(12)	(20)	(10)	(2)	(73)	..
Sardinella albella ..	20	..	..	..	..	..	..	..	..	..	..	..	20	..
	(50)	(5)	..	..	..	(4)	(54)	(2)	..	(1)	..	..	(116)	136
Sardinella fimbriata ..	27	..	3	..	..	5	1	..	9	..	..	..	45	..
	(217)	(25)	..	..	..	(6)	(5,126)	(145)	(22)	(5)	(6)	(1)	(5,553)	5,598
Sardinella longiceps ..	..	..	..	..	9	..	..	..	..	..	..	..	9	..
	(60)	..	..	..	..	..	(59)	(41)	(42)	(36)	(13)	(7)	(258)	267
Kowala coval	..	2	16	25	3	4	2	..	1	..	..	..	53	..
	(84)	(106)	(20)	(2)	(134)	(15)	(408)	(833)	(132)	(18)	(3)	(5)	(1,760)	1,813
Pellona ditchoa ..	11	34	93	310	12	10	..	..	..	..	..	..	470	..
	(1)	(1)	(3)	(1)	(9)	(3)	(14)	(1)	..	..	..	..	(33)	503
Anadontostoma chacunda ..	..	1	10	2	4	..	..	..	..	..	..	..	17	..
	(7)	(64)	(15)	(10)	(1)	(2)	..	..	..	..	..	(81)	(180)	197
Opisthopterus tardoore ..	61	583	144	31	3	30	7	1	..	89	34	78	1,061	..
	(20)	(13)	(55)	(8)	(1)	(6)	(5)	(7)	(4)	(56)	(12)	(30)	(217)	1,278
Anchoviella commersonii ..	..	..	..	15	..	3	..	44	33	1	..	..	96	..
	..	..	..	..	..	..	..	(1)	..	..	..	..	(1)	97
Anchoviella heterolobus ..	..	..	..	..	..	..	9,416	..	155	35	10	..	9,616	9,622
	..	..	..	..	..	..	(4)	..	(1)	..	(1)	..	(6)	..

Anchoviella tri ..	21 ..	78 ..	596 (5)	2,300 ..	388 (7)	1,363 ..	10 ..	208 (1)	58 (1)	35 ..	11 (2)	.. ..	5,068 (16)	.. 5,084
Thrissocles malabaricus ..	.. (12)	16 (16)	4 (13)	.. (10)	4 (4)	.. ..	.. ..	.. (41)	.. (44)	.. (56)	.. (47)	.. (63)	24 (306)	.. 330
Thrissocles mystax ..	146 (25)	564 (44)	78 (6)	149 (10)	53 (65)	39 ..	3 (158)	.. (544)	6 (232)	7 (808)	26 (443)	58 (417)	1,129 (2,752)	.. 3,881
Thrissocles purava ..	1 (1)	8 (30)	12 ..	2 (1)	.. (1)	.. ..	.. ..	.. (1)	.. (10)	.. (14)	.. (1)	.. (3)	23 (62)	.. 85
Thrissocles setirostris ..	.. (8)	1 ..	.. ..	.. ..	.. (1)	10 (24)	.. ..	.. ..	.. (1)	.. (4)	.. (5)	.. (13)	11 (56)	.. 67
Solea ovata	.. ..	3 ..	.. (8)	27 (4)	908 (80)	.. (4)	188 ..	.. ..	.. ..	.. ..	1 ..	.. ..	1,127 (96)	1,223 ..
Cynoglossus puncticeps ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. (1)	2 (6)	.. ..	15 ..	17 (7)	.. 24
Cynoglossus semifasciatus	300 ..	126 (1)	.. (1)	1 (45)	39 (20)	6 (38)	5,503 (20)	.. (35)	9 (76)	2,003 (138)	1,064 (239)	1,081 (87)	10,132 (700)	.. 10,832
Cynoglossus dubius ..	.. ..	3 ..	.. ..	2 ..	1 ..	.. ..	.. ..	.. ..	.. ..	.. ..	1 ..	6 ..	13 ..	.. 13
Megalaspis cordyla ..	.. (3)	.. (1)	.. (2)	.. ..	.. (3)	.. (1)	.. ..	.. ..	5 (1)	1 (4)	.. (3)	.. (7)	6 (25)	.. 31
Caranx djedaba ..	1 (16)	.. (8)	.. ..	.. ..	.. (2)	.. ..	.. ..	19 (6)	24 (19)	.. (20)	1 (73)	.. (3)	45 (147)	.. 192
Caranx kalla	1 (286)	.. (98)	1 (45)	.. (25)	.. ..	1 (235)	1 (15)	.. (119)	7 (39)	4 (14)	.. (17)	.. (16)	15 (909)	.. 924
Caranx sexfasciatus ..	1 (1)	.. (5)	5 (5)	3 ..	.. (4)	4 (1)	.. ..	1 ..	5 ..	.. ..	1 (4)	.. (2)	20 (22)	.. 42
Chorinemus tala ..	.. (1)	.. (3)	2 ..	.. ..	.. ..	.. (7)	.. ..	.. (1)	2 (1)	.. ..	4 ..	.. (1)	8 (14)	.. 22
Lactarius lactarius ..	17 (2)	25 (8)	285 (90)	112 (41)	14 (33)	38 (10)	4 (14)	1 (2)	.. ..	7 ..	11 ..	9 (10)	523 (210)	.. 733

APPENDIX 2—*Continued.*

Table showing the number of each species of fish caught in the boat seine and the gill net during different months of the year.

Numbers without the brackets indicate the number of specimens caught in the boat-seine.

Numbers within the brackets indicate the number of specimens caught in the gill net.

Species.	Apr. 1949	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1950	Feb.	Mar.	Totals	Total
Leiognathus insidiator ..	5 (8)	6 (2)	3 (6)	1 (2)	7 (3)	337 (5)	2 (61)	1 (19)	.. (4)	2 (5)	.. (23)	.. (3)	364 (141)	.. 505
Leiognathus ruconius ..	.. (8)	17 (17)	9 (28)	13 (16)	.. (30)	15 ..	7 (1)	.. (8)	.. ..	4 (1)	1 (3)	.. ..	66 (112)	.. 178
Leiognathus equulus ..	.. ..	.. ..	3 (5)	6 (2)	.. (2)	.. ..	.. ..	.. ..	.. ..	4 ..	.. ..	.. ..	13 (9)	.. 22
Leiognathus splendens ..	11 (1)	.. (5)	4 (89)	310 (192)	46 (256)	.. (56)	7 (18)	.. ..	.. ..	.. ..	19 (3)	.. (9)	397 (629)	.. 1,026
Leiognathus blochii ..	.. (6)	1 (1)	2 (67)	11 (1)	.. (12)	2 (96)	1 (95)	.. (16)	.. ..	.. (1)	3 (26)	.. (4)	20 (325)	.. 345
Leiognathus bindus ..	.. (2)	15 ..	.. ..	.. ..	.. ..	2 ..	.. (1)	.. ..	.. ..	.. ..	.. ..	.. ..	17 (3)	.. 20
Gerres filamentosus ..	.. ..	2 ..	8 (4)	3 ..	.. ..	2 ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	15 (4)	.. 19
Otolithes ruber ..	44 (7)	305 (26)	6 (40)	12 (33)	27 (12)	1 (2)	5 ..	.. ..	.. ..	10 (1)	20 (4)	58 (5)	488 (130)	.. 618
Otolithes argenteus ..	31 ..	.. ..	.. ..	.. (4)	.. (3)	.. ..	62 ..	.. (1)	.. ..	11 ..	6 ..	4 ..	114 (8)	.. 122
Pseudosciaena sina ..	77 (2)	244 (2)	4 (1)	4 (23)	3 ..	.. ..	.. ..	.. ..	.. ..	13 (1)	13 (4)	384 (3)	742 (36)	.. 778
Pseudosciaena sp. ..	2 ...	3 (1)	.. ..	.. ..	.. ..	.. ..	2 ..	.. ..	.. ..	.. ..	.. ..	7 ..	14 (1)	.. 15

Johnius belengeri ..	12 ..	170 (1)	8 (3)	5 (4)	.. (3)	.. (1)	1 ..	.. (10)	.. ..	30 (2)	208 (5)	30 (12)	464 (41)	.. 505
Scoliodon sorrakowah ..	.. ..	6 (1)	.. (5)	.. (1)	.. (1)	.. (5)	3 ..	1 (5)	.. (14)	.. (60)	2 (28)	4 (52)	16 (172)	.. 188
Scoliodon palasorrah ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	2 (11)	.. (5)	.. (12)	2 (28)	.. 30
Scoliodon walbeehmi ..	1 (23)	.. (6)	.. ..	1 (3)	.. (1)	.. ..	.. ..	.. ..	.. ..	.. (1)	.. ..	.. ..	2 (34)	.. 36
Tachysurus dussumieri ..	18 (1)	1 ..	.. ..	.. ..	7 (5)	.. (2)	.. ..	.. ..	.. ..	22 ..	7 ..	1 ..	56 (8)	.. 64
Osteogeneiosus militaris ..	.. (1)	.. ..	.. (2)	1 ..	.. ..	.. ..	.. ..	.. ..	1 ..	209 ..	25 (2)	196 (6)	432 (11)	.. 443
Muraenesox sp. ..	3 (1)	1 ..	.. ..	6 ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	2 ..	.. ..	12 (1)	.. 13
Eleutheronema tetradactylum	.. (1)	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. (10)	.. (23)	.. (15)	.. (6)	.. (55)	.. 55
Polydactylus plebius ..	.. (1)	45 (6)	2 (6)	.. (1)	.. ..	.. ..	.. ..	.. (1)	.. ..	.. ..	.. (1)	.. (4)	47 (20)	.. 67
Polydactylus heptadactylus	15 (1)	412 (2)	15 (17)	5 (13)	.. (1)	.. (1)	.. ..	.. (2)	.. ..	4 ..	9 ..	31 (1)	491 (38)	.. 529
Sphyraena obtusata ..	.. ..	.. ..	11 ..	3 ..	.. ..	1 ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	15 ..	.. 15
Mugil speigleri ..	.. (1)	1 (1)	85 (2)	.. ..	.. (2)	.. ..	.. (1)	.. (20)	.. ..	.. (1)	.. (1)	.. ..	86 (29)	.. 115
Mugil longimanus ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. (1)	5 (1)	1 (2)	.. ..	1 (2)	7 (6)	.. 13
Bregmaceros macclellandi ..	4 ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	4 (1)	14 ..	22 (1)	.. 23
Ambassis gymnocephalus ..	74 (9)	295 (14)	23 (53)	17 (1)	46 (6)	42 (10)	226 ..	166 (12)	202 (7)	90 (6)	117 (30)	36 (8)	1,334 (156)	.. 1,490

APPENDIX 2—*Continued.*

Table showing the number of each species of fish caught in the boat seine and the gill net during different months of the year.

Numbers without the brackets indicate the number of specimens caught in the boat-seine.

Numbers within the brackets indicate the number of specimens caught in the gill net.

Species.	Apr. 1949	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1950	Feb.	Mar.	Totals	Tota
Therapon jarbua ..	..	1	6	15	6	3	1	..	..	..	..	..	32	..
	..	..	(3)	(1)	..	..	..	..	(1)	..	..	..	(5)	37
Therapon puta ..	..	..	..	..	..	..	..	..	..	49	..	..	49	..
	..	..	(9)	..	..	..	..	..	..	..	..	..	(9)	58
Sillago sihama ..	15	..	2	..	..	..	..	..	10	3	3	..	33	..
	..	..	..	..	..	..	..	..	..	..	..	..	..	33
Scomberomorus commerson	..	..	2	..	..	..	..	..	..	..	..	..	2	..
	(10)	(5)	(2)	..	..	..	..	..	..	(3)	(3)	(6)	(29)	31
Scomberomorus guttatus ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
	(5)	(7)	(13)	(1)	(3)	..	..	(1)	..	(5)	(5)	(4)	(44)	44
Trypauchen vagina ..	..	56	..	..	..	..	..	..	..	..	..	..	56	..
	..	..	..	..	..	..	..	..	..	..	..	..	..	56
Parastromateus niger ..	..	2	3	..	..	..	..	..	..	..	2	..	7	..
	..	..	(3)	..	..	..	..	..	..	..	..	..	(3)	10
Trichiurus haumela ..	1	..	2	12	18	381	138	..	..	6	71	22	651	..
	..	..	(6)	(102)	(29)	(7)	..	(1)	..	..	..	(2)	(147)	798
Teuthis oramin ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	(13)	(1)	(3)	..	..	..	..	..	..	..	(17)	17
Pomadasys hasta ..	..	..	..	45	..	..	..	..	..	12	..	1	58	..
	..	..	(5)	(10)	(2)	(8)	..	(1)	..	..	..	..	(26)	84
Triacanthus brevirostris ..	..	..	..	..	..	..	2	3	3	8	..	..	16	..
	..	..	..	..	(2)	(1)	..	..	..	..	(1)	..	(4)	20

Tetraodon (Chelonodon) patoca.	.. ..	.. ..	2 ..	3 ..	1 ..	32 ..	4 ..	.. ..	.. ..	3 ..	.. ..	.. ..	45 ..	.. 45
Other species ..	1 (2)	8 ..	.. (3)	3 (5)	3 (1)	16 (5)	4 (1)	1 ..	2 (3)	7 (1)	1 (1)	2 (1)	48 (23)	.. 71
Total number of specimens caught in each net ..	921 (884)	3,040 (527)	1,462 (653)	3,456 (580)	1,613 (742)	2,379 (562)	15,600 (6,066)	446 (1,880)	538 (678)	2,701 (1,324)	1,682 (1,040)	2,038 (888)	35,876 (15,824)	.. 51,700
Total number of specimens for each month ..	1,805	3,567	2,115	4,036	2,355	2,941	21,666	2,326	1,216	4,025	2,722	2,926	..	51,700

A SYSTEMATIC ACCOUNT OF THE CHAETOGNATHA OF THE INDIAN COASTAL WATERS, WITH OBSERVATIONS ON THEIR SEASONAL FLUCTUATIONS ALONG THE MALABAR COAST.*

(With 14 Tables and 13 Text-figures.)

By P. C. GEORGE; *Central Marine Fisheries Research Station, West Hill, Calicut.*

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INTRODUCTION.

Our knowledge of the systematics and distribution of the Chaetognatha (Arrow-worms) of the Indian Coastal Waters, particularly of the west coast of India, is very meagre. The Chaetognaths have assumed considerable importance in recent years, as they have been regarded as useful indicators of movements of oceanic waters (vide Russell, 1937; Kemp, 1938), which have a bearing on fishery problems. The present paper is an attempt to describe in detail the systematics of the Indian genera and species and the seasonal variations in the occurrence of the Chaetognatha along the Malabar Coast with reference to the changes in the hydrographical factors.

The Indo-pacific region is rich in Chaetognatha as is evident from the results of the *Siboga*, *Albatross* and *Sea-lark* expeditions. Aida (1897) and Tokioka (1938 to 1942) have drawn attention to the richness of the group in Japanese waters. Doncaster (1903) described a number of new species from the seas around Maldive and Laccadive islands, many of which were, however, shown by later workers to be synonyms of already described forms.

The only detailed description of Indian coastal species is that by John (1933 and 1937) based on collections made at Madras. Subramaniam (1940) recorded *S. bedoti* Beraneck from the same collection disputing John's conclusions in regard

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to the systematic position of certain species. Varadarajan and Chacko (1942) recorded in the Krusadai area the forms already described by John in addition to *Spadella cephaloptera* and *Krohnia pacifica*. Menon (1945) and Pillai (1945, abstract only) have studied the *Sagitta* of the Trivandrum coast of which two (*S. enflata* and *S. bedoti*) are fairly common and the remaining three are somewhat rare and only occasionally found in the plankton. Two of the three species of *Sagitta* of the Bombay Harbour considered distinct by Lele and Gae (1936) have been referred by George (1949) to *S. enflata* and *S. robusta*.

Material and Methods.

Material for this investigation was collected mainly from the triweekly plankton hauls from the foreshore and offshore waters, off West Hill, three miles north of Calicut in the Malabar District along the West Coast of India (75° 46′ E. and 11° 17′ N.). Plankton was always collected from a point two miles away from the coast (station A) for a period of half an hour between 5 a.m. and 6 a.m. on alternate days so as to maintain uniformity of samples. The studies on the seasonal variations in the distribution of chaetognaths were made from horizontal hauls obtained during a period of twelve months. The specimens found in the other hauls in this area, and those obtained from the offshore area (station B) were made use of in the preparation of the key of diagnostic characters. Samples of chaetognaths obtained from plankton in Madras, Gulf of Manaar, Karwar and Bombay coasts provided material for the additions to descriptions of species. The material collected was preserved in 5% formalin and fractionated by means of Lea-Gibbons Sub-Sampler, and the number of specimens and species, and the morphological peculiarities noted. As far as possible fresh material was used in drawing up a table of diagnostic features, as the preserved material showed a certain amount of shrinkage, especially in the region of the fins and tactile bodies. For the accurate recording of the body proportions and fins, transparent stained specimens were more useful. A 3 to 5 minute immersion in 10% alcoholic solution of Cotton-blue gave good results for staining the fins and body. For studying the nature and pattern of the corona ciliata, specimens previously treated with Cotton-blue were allowed to remain for five minutes in a 1% aqueous solution of methylene blue. This method gave excellent results for delineating the important morphological details. The sketches were made with a camera lucida. All measurements were taken with the help of a counting slide with one mm. squares.

The hydrographical data correlated with the catches are Salinity, Rain-fall and Temperature. Salinity was determined by the Oxner and Knudsen method as described by Harvey. The standard silver nitrate solution was checked by standard sea water supplied by Laboratoire Hydrographique, Copenhagen, and corrected with the help of Harvey's salinity correction table.

The classification adopted in this account is mainly that of Michael (1919) based on Ritter Zahony's works (1911). Burfield and Harvey's (1926) account of the *Sea-lark* chaetognatha was useful as it included a large number of forms from the Indian Ocean and redescriptions of many of Doncaster's species. In drawing up a detailed account of the Indian genera and species, the taxonomic features of the specimens already recorded from Indian, Australian and Japanese waters were found useful (vide Fowler, 1906; Doncaster, 1903; Thomson, 1947; Aida, 1897 and Tokioka, 1938 to 1942). The most serious difficulty in the identification of chaetognatha is the close similarity of several species of *Sagitta*. Hence a key to genera and species of Indian forms is provided, based on such characters that are found not to vary with growth or maturity and that could be made out without much difficulty. A table of diagnostic features is appended at the end of the chapter on systematics, and tables of percentage measurements showing the possible variations within the species are given at the end of the description of each species,

hoping that these would prove more useful than a lengthy discussion of the comparison of specific characters.

ACKNOWLEDGEMENTS.

I am indebted to Dr. H. Srinivasa Rao and to Dr. B. S. Bhimachar for valuable suggestions and encouragement. I am grateful to Dr. N. K. Panikkar for drawing my attention to some aspects of the studies on the systematics and for the kind loan of literature. My thanks are also due to my colleague Mr. K. H. Mohamed for help in the preparation of the illustrations.

KEY TO GENERA OF INDIAN *CHAETOGNATHA* AND KEY TO INDIAN SPECIES OF *SAGITTA*.

Key to genera.

Collarette present, uniformly massive spreading over the single pair of lateral fins	*Pterosagitta*	
Collarette absent or not at all massive		1
1. Posterior pair of lateral fins confined entirely to tail segment	*Spadella* *	
Posterior pair of lateral fins extending over trunk and tail segments		2
2. Single pair of lateral fins	*Krohnitta*	
Two pairs of lateral fins	*Sagitta*	

Key to species of Indian Sagitta.

Collarette present		1
Collarette absent	*S. enflata*	
1. Corona ciliata elongate or looplike arising between or behind eyes		2
2. Tail-septum without any constriction		3
Tail-septum with a pronounced constriction	*S. tenuis*	
3. Collarette extends up to the anterior pair of fins		4
Collarette does not extend up to the anterior pair of fins		6
4. More than 70% of the posterior pair of fins situated on the trunk	*S. planktonis*	
Less than 70% of the posterior pair of fins situated on the trunk		5
5. Corona ciliata elongate arising in between eyes with the lateral fins of equal length or one slightly longer than the other	*S. robusta*	
Corona ciliata hour-glass shaped arising far behind the eyes with posterior pair of lateral fin nearly one and a half times as long as the anterior pair	*S. regularis*	
6. Paired fins rayless anteriorly		8
Paired fins fully rayed		7
7. Body hispid throughout and corona ciliata arising in between eyes with tactile bodies on the fins	*S. hispida*	
Body not hispid and corona ciliata arising behind the eyes with less than 50% of the fin lying in front of tail septum; tactile prominences absent	*S. neglecta*	
8. Anterior pair of fins very long, always more than 30% of the body length	*S. pulchra*	
Anterior pair of fins not very long, always less than 30% of the body length	*S. bedoti*	

DESCRIPTIVE ACCOUNTS OF SPECIES.

Genus *SAGITTA*, Quoy and Gaimard, 1827.

1. *SAGITTA PULCHRA*, DONCASTER, 1903.

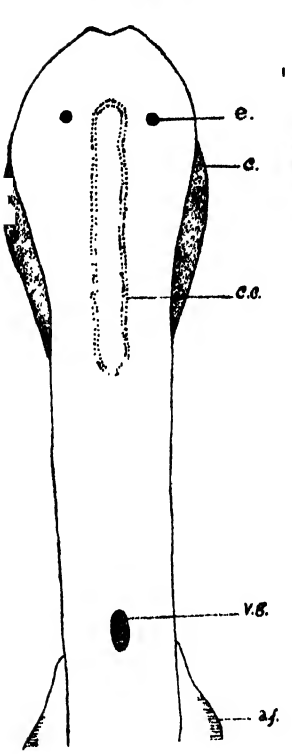
Sagitta pulchra, Doncaster, 1903; Fowler, 1906; Michael, 1919.

This species is not common along the east and west coasts of India. It is intermediate between the 'enflata type' with very thin transparent body and the

* This genus was unrepresented in the present collections, but *Spadella cephaloptera* was previously recorded from Krusadai (Varadarajan and Chacko, 1942) and Trivandrum (Menon, 1945) coasts.

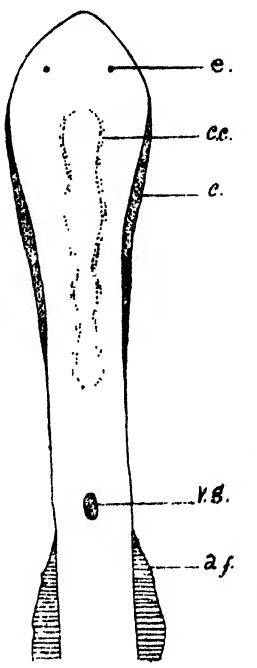
'robusta type' with opaque body and strong musculature. The body is translucent with strong body wall and does not shrink on preservation.

The head is amall and narrow. The collarette is short, never extends up to the ventral ganglion, and stops less than half the distance from neck to the ganglion (Text-fig. 1). The anterior fin is very long, and always more than 30% of the

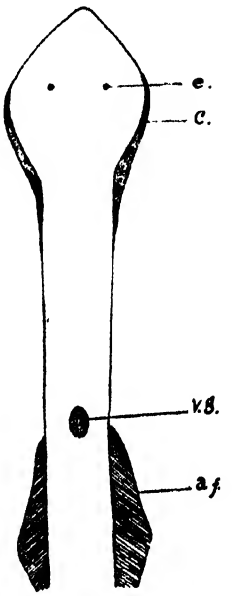


TEXT-FIG. 1.
S. pulchra

TEXT-FIG. 2.
S. planktonis



TEXT-FIG. 3.
S. neglecta



TEXT-FIG. 4.
S. tenuis

total length of the animal, and begins at the base of, or up to, the anterior end of the ventral ganglion but with no connection between it and the collarette. The narrow rayless anterior part of the fin is without extensions into the base of the fin. The shorter posterior fin, which arises close to or immediately behind the anterior is very similar, with more than 50% of its length in the trunk region and extending posteriorly up to the seminal vesicle. The tail region is pointed with the tail fin triangular and fully rayed. The slight constriction at the tail region is visible through the moderately opaque body. The narrowly oblong, relatively short, corona ciliata originates between the eyes, and extends up to the hind end of the collarette. Two-thirds of its length is situated on the trunk region. There are 5 to 8 extremely slender and very much curved prehensile jaws. The anterior and posterior teeth vary in number from 6 to 8 and 8 to 14 respectively.

The species occurs along with *Sagitta enflata* and *Sagitta bedoti*, and can be easily distinguished from the former by the absence of rays in the anterior region and from the latter by the extremely long anterior fin and the inappreciable distance between the fins.

Distribution.—This rare form was recorded for the first time in Indian coastal waters by George (1949) from a collection made in the Bombay Harbour. It is also found in very small numbers in the plankton samples of Bombay, Calicut, Madras and Mandapam. Tokioka (1939) records it from Japanese waters as a rare one.

SAGITTA PULCHRA.

**Table of percentage measurements.*

Specimen Number.	Length in mm.	Width.	Length of tail.	Tail to ventral ganglion.	Length of ventral ganglion.	Posterior fin.					Anterior fin.			Collarette.		Number of anterior teeth.	Number of posterior teeth.	Number of prehensile jaws.
						Length.	Width.	To seminal vesicle.	To anterior fin.	Tail-septum †.	Length.	Width.	To ventral ganglion.	Length.	To ventral ganglion.			
I	14·0	6·0	24·0	70·0	5·2	27·0	5·2	1·0	2·5	56·2	32·0	3·4	+1·0	6·0	11·0	7–6	12–11	6–6
II	10·0	5·6	24·5	69·0	5·6	26·8	5·0	0·0	3·0	52·0	31·7	3·0	+0·5	6·0	12·0	6–7	12–11	6–5
III	12·5	5·6	25·0	70·0	5·2	25·5	4·8	0·0	2·0	55·0	32·8	2·8	+0·8	5·5	11·5	5–6	12–11	5–6
IV	9·8	5·0	25·0	70·0	5·8	27·0	4·2	0·0	2·0	51·0	32·0	2·8	+0·5	6·0	12·8	6–7	12–12	6–6
V	12·2	5·3	26·0	69·5	5·6	25·2	5·5	1·0	3·0	57·0	32·5	2·9	+0·5	5·0	11·1	7–7	12–10	6–6
VI	10·6	5·8	25·0	70·0	5·5	26·0	4·6	1·0	2·8	54·0	31·9	2·8	+0·7	5·0	11·0	8–8	12–14	5–6

* In this and in the subsequent tables of measurements, the armature counts in the last three columns are given in absolute numbers; in other columns the size of the part in question is expressed as a percentage of the total length of the animal.

† Denotes percentage of fin lying in front of the tail-septum.

2. *SAGITTA PLANKTONIS*, STEINHAUS, 1896.

Sagitta planktonis, Steinhaus, 1896; Michael, 1919; Burfield and Harvey, 1926
Sagitta planktonis+*Sagitta zetesios*, Fowler, 1906.

Sagitta planktonis occurs along with *S. robusta*. John (1937) considers it to be a rare form on the Madras coast.

The body is opaque and the head is moderately large in size. The uniformly narrow and very long collarette extends up to the ventral ganglion, sometimes up to the anterior fin. (Fig. 2). The ventral ganglion occupies a unique position in that it is reached both by the collarette and the anterior fin on either side. The anterior fin is narrow and slightly longer than the posterior fin. Usually, the fins are very close together but in some cases they are confluent. The posterior fin is broader than the anterior with the rays of the paired fins not reaching the base. The seminal vesicle is situated just at the base of the posterior fin and far above the tail fin, as observed by Tokioka (1940) in those collected from the Japanese waters.

Distribution.—*S. planktonis* is scarce in all the collections. Plankton from Madras and Malabar showed a few ill-preserved ones.

3. *SAGITTA NEGLECTA*, AIDA, 1897.

Sagitta neglecta, Aida, 1897; Fowler, 1906; Michael, 1911; John, 1933; Tokioka, 1939.

Sagitta neglecta occurs on the east and west coasts of India along with *S. bedoti* and *S. enflata*. It has been recorded previously from the Madras coast by John (1933) and from the Gulf of Manaar by Varadarajan and Chacko (1942).

S. neglecta is medium-sized, generally opaque, with a slender body and prominent head. The species could also be easily distinguished by the less opaque tail. There is no pronounced constriction between the body and the tail which is continued uninterrupted from the trunk. Head is conspicuous and the neck is masked by a prominent collarette and thick epidermis. The collarette is narrow and extends to nearly half the distance from the neck to the ventral ganglion (Fig. 3). The long, and broadly sinuous corona ciliata is situated mostly on the trunk, the anterior part beginning from the neck. It extends downwards towards the ventral ganglion. The small and narrow anterior fin begins from the level of the ganglion. The posterior fin is broader and longer but usually never extends to the seminal vesicle. Both the fins are fully rayed. The triangular tail fin is situated below the seminal vesicle which is prominently oval in shape.

Distribution.—*S. neglecta* was obtained in the plankton throughout the year but in larger numbers soon after the South-West Monsoon.

4. *SAGITTA TENUIS*, CONANT, 1896.

Sagitta tenuis, Conant, 1896; Michael, 1919; John, 1933.

This is one of the smallest species of *Sagitta* of these coasts, 5 to 6 mm. long. It was taken in large numbers from July to September on the Trivandrum coast (Menon, 1945). John (1933) and Varadarajan and Chacko (1942) recorded it from the east coast.

The body is slender and opaque and is often found broken up into bits in preserved collections. Head is small and the neck is prominent although a short collarette is present. The collarette is very narrow and inconspicuous and does not extend to more than one-fourth the distance to the ganglion (Fig. 4). The body is also narrow with a slight bulge in the middle region. The tail region is very

SAGITTA PLANKTONIS.

Table of percentage measurements.

Specimen Number.	Length in mm.	Width.	Length of tail.	Tail to ventral ganglion.	Length of ventral ganglion.	Posterior fin.					Anterior fin.			Collarette.		Number of anterior teeth.	Number of posterior teeth.	Number of prehensile jaws.
						Length.	Width.	To seminal vesicle.	To anterior fin.	Tail-septum.	Length.	Width.	To ventral ganglion.	Length.	To ventral ganglion.			
I	13·0	8·0	25·0	68·0	3·8	21·0	4·5	0·0	2·0	75·5	23·5	2·8	0·0	24·0	0·0	7–8	16–17	8–9
II	12·5	7·0	24·6	69·0	4·0	20·0	4·0	0·0	1·0	72·0	23·0	3·0	0·0	23·0	0·0	7–8	16–18	8–8
III	11·8	5·0	24·5	68·0	4·2	20·5	4·0	0·0	1·5	75·0	23·1	3·0	0·0	23·5	0·0	7–7	16–16	8–8
IV	13·0	5·8	25·1	68·5	4·0	20·8	3·8	0·0	0·0	74·0	23·7	3·1	0·0	24·0	0·0	8–8	16–?	8–9
V	12·6	6·0	25·0	69·0	3·5	21·0	4·2	0·0	1·0	74·0	23·0	2·9	0·0	24·1	0·0	8–7	16–15	8–9
VI	12·0	6·1	25·2	69·1	3·8	21·3	4·5	0·0	1·2	73·8	23·0	3·0	0·0	24·0	0·0	8–8	17–18	8–8

SAGITTA NEGLECTA.

Table of percentage measurements.

Specimen Number.	Length in mm.	Width.	Length of tail.	Tail to ventral ganglion.	Length of ventral ganglion.	Posterior fin.					Anterior fin.			Collarette.		Number of anterior teeth.	Number of posterior teeth.	Number of prehensile jaws.
						Length.	Width.	To seminal vesicle.	To anterior fin.	Tail-septum.	Length.	Width.	To ventral ganglion.	Length.	To ventral ganglion.			
I	7·1	5·0	32·0	68·6	6·5	24·5	4·5	1·8	6·8	40·2	20·3	3·0	0·0	13·0	5·5	5–6	14–17	6–7
II	7·15	4·8	31·9	69·0	6·8	25·0	4·2	1·9	6·5	41·0	21·1	3·0	0·0	12·5	5·6	5–7	14–18	6–8
III	7·0	5·0	31·8	68·5	6·4	25·1	4·6	2·0	6·7	40·0	21·0	3·1	−1·0	13·2	5·4	5–7	14–18	6–7
IV	7·2	5·1	31·9	65·5	6·8	26·0	4·0	2·0	7·0	42·0	21·5	3·0	0·0	13·1	5·8	5–6	15–18	7–7
V	7·4	5·3	32·8	69·0	6·1	26·2	3·8	1·9	6·9	41·0	22·0	2·9	0·0	12·8	5·7	6–7	14–17	6–7
VI	7·5	5·0	33·0	70·0	5·9	24·5	3·5	1·8	7·2	39·0	20·2	2·2	0·0	12·8	5·5	5–7	14–16	7–8
VII	6·9	4·9	31·9	68·0	6·3	22 5	3·4	2·1	8·1	42·0	19·0	2·9	−1·2	12·5	5·8	5–7	15–16	6–6
VIII	7·6	5·2	33·0	71·0	6·0	23·8	5·5	1·6	7·6	38·5	19·0	4·0	0·0	12·5	6·0	5–7	14–16	6–7
IX	7·5	5·3	32·8	70·0	6·0	26·2	5·4	1·7	8·2	39·0	22·1	3·8	0·0	12·6	6·2	5–7	15–15	6–7
X	7·5	5·3	33·0	69·0	6·1	26·0	5·3	1·6	8·1	39·5	21·8	3·5	0·0	12·6	6·0	5–8	14–17	6–7

SAGITTA TENU--.

Table of percentage measurements.

Specimen Number.	Length in mm.	Width.	Length of tail.	Tail to ventral ganglion.	Length of ventral ganglion.	Posterior fin.					Anterior fin.			Collarette.		Number of anterior teeth.	Number of posterior teeth.	Number of prehensile jaws.
						Length.	Width.	To seminal vesicle.	To anterior fin.	Tail-septum.	Length.	Width.	To ventral ganglion.	Length.	To ventral ganglion.			
I	5·5	4·1	26·0	68·0	5·6	24·5	4·2	4·0	4·1	43·0	14·0	2·5	0·0	2·2	13·5	7–7	7–8	8–8
II	5·1	4·0	25·1	65·0	5·5	25·0	4·2	3·2	4·0	41·0	14·1	2·2	−1·0	2·0	14·0	6–7	7–7	8–8
III	5·0	4·5	27·0	65·0	5·8	24·8	4·3	3·2	4·2	42·0	13·8	2·5	−1·5	2·1	14·2	6–7	7–8	8–7
IV	5·3	4·0	26·5	67·0	5·7	24·5	4·2	3·5	3·8	42·5	14·0	2·5	0·0	2·3	14·0	5–6	8–8	8–7
V	5·0	5·0	25·0	64·0	5·5	23·9	4·0	3·2	4·1	41·0	14·1	2·3	0·0	2·2	14·2	5–7	8–7	8–8
VI	5·4	4·8	28·0	65·5	5·6	24·5	4·2	3·3	3·5	41·5	13·8	2·6	0·0	2·4	13·8	7–7	7–8	8–7
VII	5·3	4·5	26·5	65·0	5·5	24·1	4·3	3·1	3·5	42·0	13·6	2·5	−1·8	2·1	14·3	5–7	7–7	7–7
VIII	4·9	4·6	27·1	65·0	5·2	25·0	4·0	3·8	4·2	41·8	13·9	2·5	−2·0	2·3	14·1	7–8	6–7	8–8
IX	5·6	4·9	26·0	67·0	5·6	24·5	4·5	3·0	3·8	42·5	14·1	2·4	0·0	2·2	13·8	5–6	6–7	8–7
X	5·7	5·0	26·2	67·5	5·5	24·6	4·6	3·1	3·6	42·0	14·0	2·5	0·0	2·1	14·0	7–7	6–7	8–7

prominent due to the presence of a thick constriction at the tail septum. The wart-like prominences seen in front of the septum on either side are the openings of the oviducts.

The short and narrow anterior fin arises from the level of the ventral ganglion or even slightly below, but never above it. The posterior fin is half elliptical, longer and broader than the anterior fin. Both the fins are completely rayed. The small seminal vesicle is situated between the posterior and tail fins. The triangular tail region is as opaque as the trunk region.

Distribution.—On the Madras coast *S. tenuis* was uniformly present but on the Malabar coast it was scarce except during the monsoon.

5. *SAGITTA BEDOTI*, BERANECK, 1895.

Sagitta bedoti, Beraneck, 1895; Michael, 1919; Lele and Gae, 1936; Subramaniam, 1940.

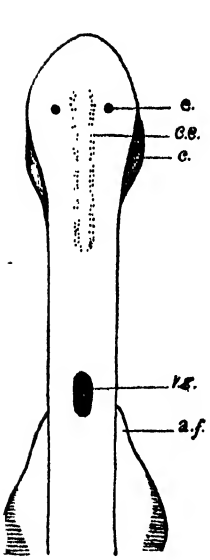
Sagitta bipunctata, Aida, 1897.

Sagitta polyodon, Doncaster, 1903.

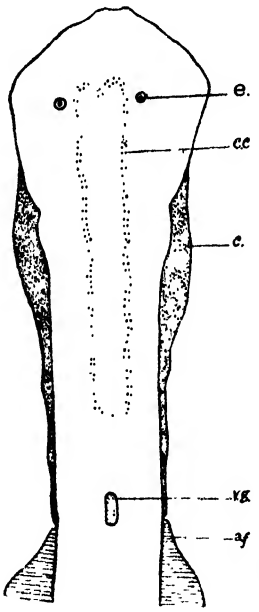
Sagitta bedoti, forma *typica*, Tokioka, 1942.

S. bedoti is one of the commonest species of *Sagitta* of the Malabar coast. It was previously recorded from the Bombay (Lele and Gae, 1936; George, 1949) and Madras coasts (Subramaniam, 1940).

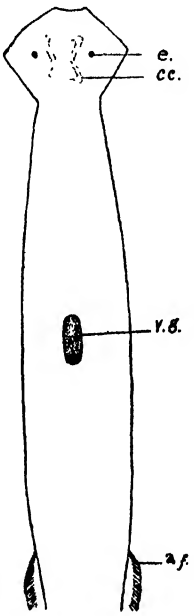
The small head is followed by the semitransparent and needle-shaped body. Fowler (1906) found a slight thickening of the epidermis of the neck instead of a real collarette in the *Siboga* specimens of *S. bedoti*. But Ritter Zahony (1911), Michael (1919) and Burfield and Harvey (1926) observed short but conspicuous collarettes. Lele and Gae (1936) thought that the short slightly thickened epidermis represented the collarette. As in the Japanese specimens (Tokioka, 1940) a distinct collarette is present in my specimens (Fig. 5). It is short, extending to less than



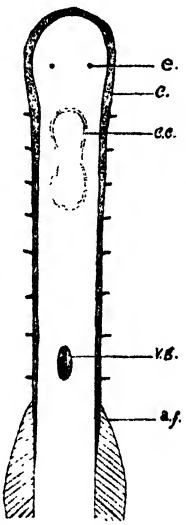
TEXT-FIG. 5. *S. bedoti.*



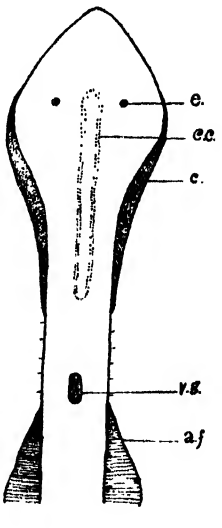
TEXT-FIG. 6. *S. robusta.*



TEXT-FIG. 7. *S. enflata.*



TEXT-FIG. 8. *S. regularis.*



TEXT-FIG. 9. *S. hispida.*

SAGITTA BEDOTI.

Table of percentage measurements.

Specimen Number.	Length in mm.	Width.	Length of tail.	Tail to ventral ganglion.	Length of ventral ganglion.	Posterior fin.					Anterior fin.			Collarette.		Number of anterior teeth.	Number of posterior teeth.	Number of prehensile jaws.
						Length.	Width.	To seminal vesicle.	To anterior fin.	Tail-septum.	Length.	Width.	To ventral ganglion.	Length.	To ventral ganglion.			
I	9·5	5·6	28·5	72·6	5·5	24·4	4·1	0·0	3·5	48·0	27·4	2·5	0·0	3·1	14·2	10–11	21–23	7–7
II	9·8	5·5	28·0	72·1	5·9	24·6	4·2	0·0	3·2	48·5	27·5	2·5	0·0	3·1	14·5	10–11	21–23	7–8
III	10·0	5·9	28·1	72·8	5·6	25·0	4·0	0·0	3·2	48·0	27·9	2·4	0·0	3·1	14·9	11–11	20–21	8–8
IV	10·5	5·8	27·5	71·8	5·5	27·0	4·5	0·0	3·3	49·2	28·5	2·7	0·0	3·2	14·3	10–12	20–21	8–8
V	12·0	6·0	27·2	69·0	5·5	26·8	4·2	0·0	3·1	49·0	29·1	2·5	0·0	3·2	14·0	12–13	21–23	8–8
VI	13·1	6·2	27·2	69·1	5·4	26·0	4·0	0·0	3·2	49·1	28·0	2·2	0·0	3·8	14·3	12–11	21–23	8–8
VII	13·5	6·3	27·1	69·5	5·6	26·5	4·1	0·0	3·2	48·2	28·0	2·5	0·0	4·1	14·5	12–13	21–23	8–7
VIII	13·7	6·3	25·9	70·0	5·0	26·1	4·6	0·0	3·3	48·2	28·2	2·9	0·0	4·0	14·2	12–13	20–22	8–8
IX	13·8	6·2	25·6	70·0	5·5	26·5	4·5	0·0	3·4	46·5	28·6	2·8	0·0	4·0	14·5	11–12	22–22	8–8
X	14·5	6·5	24·8	69·5	5·4	26·5	4·4	0·0	3·4	46·1	29·0	2·8	+0·5	4·1	14·9	11–13	24–22	8–8

half the distance to the ventral ganglion. The long and narrow corona ciliata arises slightly in front of the eyes and extends to two-thirds the distance towards the ventral ganglion.

The anterior fin extends up to the level of the ventral ganglion, and in large specimens even slightly beyond. The anterior half of both the fins is rayless. The anterior fin is less than a third as long as the animal, which is in contrast to the condition found in *S. pulchra*. The posterior fin is never longer than the anterior fin and more of it lies behind the tail septum. The elongated seminal vesicle is in close contact with the posterior fin and caudal fins. The vesicle is less prominent at the anterior end than in that of *S. robusta*. The tail is continuous with the trunk and without any constriction. The trunk is more or less of uniform width except in the region of the anterior fin where it is slightly wider.

Both rows of teeth show uneven tips. The closely arranged posterior teeth which are as many as 29, give them an appearance of being set in two rows one above the other.

Distribution.—*S. bedoti* occurs in large numbers along both the coasts of India. They form a great part of the collections made in Madras, Mandapam, Calicut and Bombay.

6. *SAGITTA ROBUSTA*, DONCASTER, 1903.

Sagitta robusta, Doncaster, 1903; Burfield and Harvey, 1926; George, 1949.
Sagitta hispida, Aida, 1897.
Sagitta ferox, Doncaster, 1903; Michael, 1919.
Sagitta bombayensis, Lele and Gae, 1936.

This is the most 'robust' chaetognath in the collections from our coasts which shows great variations in the nature of the collarette and the fin length (vide Burfield and Harvey, 1926). George (1949) has shown that *S. bombayensis* Lele and Gae (1936) is a synonym of *S. robusta* Doncaster.

The maximum length attained by *S. robusta* in my collections is 17 mm. Body is opaque and the head is relatively large and broad. Tail is about $\frac{1}{4}$ the total length of the animal. Epidermis is thick all over the body length and particularly so behind the head. The head is broader than the trunk and the neck is almost masked by the well-developed collarette which may extend up to the ventral ganglion reaching even the anterior pair of fins. The collarette is more than a fourth as broad as the body is wide (Fig. 6). The ventral ganglion is generally slightly in front of the anterior fin and covered over by the collarette. As the table of measurements shows these characters are highly variable. The elongate corona ciliata arises between or slightly in front of the eyes extending backwards into the trunk.

The narrower anterior fin may be shorter than, as long as, or longer than, the posterior. In most of the East Coast specimens the anterior fin is slightly longer than the posterior, which in John's (1933) opinion characterises the Philippine forms. The posterior fins are generally as long as the anterior fin but may be longer or shorter than the latter. The broader posterior fin which extends up to the seminal vesicle has more than 50% of its length in the tail segment, and is broadest behind the tail septum.

Distribution.—*S. robusta* is a typical warm-water species found in the collections from Bombay, Karwar, Calicut and Madras. Specimens from inshore collections show a range in length from 7 to 13 mm., while those obtained offshore were much larger.

SAGITTA ROBUSTA.

Table of percentage measurements.

Specimen Number.	Length in mm.	Width.	Length of tail.	Tail to ventral ganglion.	Length of ventral ganglion.	Posterior fin.					Anterior fin.			Collarette.		Number of anterior teeth.	Number of posterior teeth.	Number of prehensile jaws.
						Length.	Width.	To seminal vesicle.	To anterior fin.	Tail-septum.	Length.	Width.	To ventral ganglion.	Length.	To ventral ganglion.			
I	10·0	6·6	25·5	68·0	3·5	28·5	5·0	0·0	3·8	48·0	29·0	3·8	0·0	10·0	−5·0	8–9	10–12	8–8
II	10·5	6·0	26·5	69·0	3·1	30·0	4·5	0·0	3·1	48·5	30·0	3·9	+1·5	12·0	0·0	8–8	11–15	8–8
III	10·9	5·9	25·5	68·0	3·5	30·0	5·6	0·0	2·5	43·3	29·6	3·7	+2·0	22·0	+2·0	8–9	16–17	6–7
IV	11·5	6·5	30·5	69·6	4·2	29·0	5·5	0·0	3·0	44·5	29·0	4·9	+1·5	18·3	+2·1	8–8	15–17	6–8
V	12·0	6·0	26·5	70·0	4·0	28·5	4·8	0·0	3·3	46·5	29·0	3·8	+0·5	19·0	+1·0	8–7	12–14	8–8
VI	13·5	6·5	25·8	68·5	3·8	28·9	4·5	0·0	3·5	48·0	29·2	3·9	+1·2	18·9	+1·5	8–8	15–16	8–9
VII	13·6	6·1	26·2	69·0	3·9	28·0	4·2	0·0	3·5	46·9	28·0	3·5	+1·5	11·6	+2·0	8–9	15–15	6–8
VIII	15·8	6·2	26·0	70·0	3·6	27·8	4·6	0·0	3·1	48·5	28·2	3·5	+2·1	11·5	+2·0	8–9	15–15	8–8
XI	16·0	6·4	25·0	68·9	4·0	27·6	4·8	0·0	3·6	46·5	28·9	3·3	+2·0	12·0	0·0	9–9	15–16	8–9
X	16·2	6·5	25·1	68·8	4·0	29·0	4·5	0·0	3·5	47·0	29·5	3·8	+2·2	9·5	−3·5	8–9	15–17	8–7

7. *SAGITTA ENFLATA*, GRASSI, 1881.

Sagitta enflata, Grassi, 1883; Aida, 1897; Doncaster, 1903; Fowler, 1906; Michael, 1919.
Sagitta gardineri, Doncaster, 1903.
Sagitta flaccida, Doncaster, 1903.
Sagitta enflata+*Sagitta gardineri*, John, 1933.
Sagitta gardineri, Lele and Gae, 1936.

This is the most common species of *Sagitta* of both the coasts of India.

The tumid, transparent body with its thin wall presents an 'inflated' appearance. The broad and opaque head is separated from the trunk by a distinct neck (Fig. 7), which is without a collarette. The corona ciliata is limited entirely to the head region. The trunk is widest in the middle. The tail region is extremely narrow and is marked from the rest of the body by a moderately pronounced constriction.

Fins are very transparent, delicate and completely rayed, and except in the tail fin the rays do not reach up to the base. The anterior fin is generally slightly shorter than the posterior fin, but may be as long, and is semi-elliptical in shape. It is situated far down below the ventral ganglion, the distance between the two varying from 12 to 21 per cent of the total length of the body. In preserved specimens this distance varies, with the anterior fin often much less conspicuous than it is in fresh ones due probably to great shrinkage in this region.

The posterior fin is always much broader and longer than the anterior fin. Distance between the paired fins is always more than 8% of the total length of the animal, with the result that they are never confluent. More than 60% of the posterior fin lies on the trunk. The small, spherical seminal vesicle is situated far below the posterior fin almost touching the base of the tail fin, and its glandular and non-glandular areas cannot be differentiated. Tokioka (1939) considers this type of seminal vesicle as the most primitive type as it lacks differentiation into 'head' and 'trunk' regions.

The short tail is always less than $\frac{1}{4}$ its total length and when compared to the inflated trunk the tail is inconspicuous. The body is so transparent that the tail septum is easily seen through. The triangular tail fin is fully rayed.

Distribution.—*S. enflata* is the commonest chaetognath in all my collections, especially in the December to May period. It is rare in the collections of the monsoon season. John (1933) and Michael (1911) have apparently seen small-sized specimens of 12–13 and 15–21 mm. length in the Madras and San Diego collections. Specimens in my collection are as long as 24 mm., especially those obtained from Gulf of Manaar and from the offshore station at Calicut. The specimens obtained from the inshore waters were, however, relatively small as in the length ranges recorded by John.

8. *SAGITTA REGULARIS*, AIDA, 1897.

Sagitta regularis, Aida, 1897; Doncaster, 1903; Fowler, 1906; Burfield and Harvey, 1926.

S. regularis is another small chaetognath which never seems to attain a length of more than 7 mm. This species does not occur in such large numbers as *S. enflata* or *S. bedoti*, but is fairly common during the hot months.

The head is small and inconspicuous. Eyes are large and prominent. The body is small and narrow. The tactile hairs are regularly arranged on either side of the trunk, more so in the anterior region. The well-defined collarette extends to the ventral ganglion and sometimes to the anterior fin. The collarette is of

SAGITTA ENFLATA.

Table of percentage measurements.

Specimen Number.	Length in mm.	Width.	Length of tail.	Tail to ventral ganglion.	Length of ventral ganglion.	Posterior fin.					Anterior fin.			Collarette.		Number of anterior teeth.	Number of posterior teeth.	Number of prehensile jaws.
						Length.	Width.	To seminal vesicle.	To anterior fin.	Tail-septum.	Length.	Width.	To ventral ganglion.	Length.	To ventral ganglion.			
I	11·4	12·0	19·0	69·0	4·1	16·0	4·0	5·0	8·8	69·0	13·0	2·2	17·5	..	..	7–8	12–14	8–8
II	13·6	10·6	20·0	70·0	4·0	17·5	4·5	4·8	8·3	70·0	12·4	2·5	17·0	..	..	7–7	12–13	7–8
III	14·0	10·5	18·5	68·0	3·9	17·0	4·0	5·0	8·5	66·7	14·0	2·3	17·0	..	..	7–7	12–13	7–8
IV	15·0	10·0	18·9	71·5	4·0	16·0	4·0	4·8	10·0	66·0	13·0	2·3	19·0	..	..	7–8	12–14	8–8
V	16·5	10·7	18·1	72·0	4·2	19·3	4·1	5·1	8·3	63·9	15·5	2·2	17·8	..	..	7–8	12–13	8–8
VI	18·0	10·0	18·5	71·0	4·0	18·0	4·5	5·0	8·4	66·0	15·9	2·2	17·2	..	..	7–7	12–13	8–6
V II	19·50	9·8	19·0	71·5	4·1	16·0	4·3	4·5	9·0	69·0	13·0	2·5	16·9	..	..	7–8	12–14	8–7
VIII	20·0	10·1	18·8	69·0	4·1	17·0	4·0	4·8	9·0	65·3	13·7	2·1	16·8	..	..	7–7	13–14	8–8
IX	21·5	10·2	19·0	72·0	4·1	17·4	4·2	4·6	8·8	66·0	16·0	2·2	17·0	..	..	7–8	12–13	7–8
X	24·0	10·7	18·2	73·5	4·0	17·5	4·2	4·5	8·9	64·0	12·3	2·1	16·5	..	..	7–8	12–14	8–8

SAGITTA REGULARIS.

Table of percentage measurements.

Specimen Number.	Length in mm.	Width.	Length of tail.	Tail to ventral ganglion.	Length of ventral ganglion.	Posterior fin.					Anterior fin.			Collarette.		Number of anterior teeth.	Number of posterior teeth.	Number of prehensile jaws.
						Length.	Width.	To seminal vesicle.	To anterior fin.	Tail-septum.	Length.	Width.	To ventral ganglion.	Length.	To ventral ganglion.			
I	5·9	6·5	33·5	70·0	4·0	29·0	12·0	0·0	7·0	35·0	21·0	7·5	3·3	33·0	+4·5	3–3	6–6	6–8
II	6·0	6·2	33·0	69·0	4·2	29·5	11·5	0·0	7·2	35·5	21·2	6·8	3·0	32·0	+5·0	3–4	6–6	6–8
III	5·8	6·4	34·0	70·2	4·1	28·2	11·8	0·0	7·0	35·6	20·8	7·0	3·1	31·5	+4·5	3–4	6–5	6–8
IV	5·7	6·3	34·1	69·0	4·2	28·5	11·5	0·0	7·2	34·8	20·9	6·8	3·1	31·0	+4·2	4–4	6–4	6–8
V	5·9	6·0	34·0	67·0	4·0	29·0	12·0	0·0	7·1	35·5	21·1	7·2	3·0	32·0	+4·1	4–4	6–6	6–8
VI	5·4	6·0	35·0	68·0	4·0	29·8	10·8	−1·0	6·8	34·5	22·0	7·1	3·0	32·0	+4·0	3–4	5–5	8–8
VII	5·7	6·2	34·1	65·0	4·2	30·0	11·0	0·0	7·15	34·7	22·0	6·8	3·2	32·5	+4·5	2–4	6–6	6–8
VIII	5·8	6·35	34·2	67·0	4·3	29·1	11·2	0·0	7·20	35·5	21·0	6·7	3·2	33·0	+4·4	2–4	6–5	8–?
IX	5·8	6·30	34·0	68·2	4·3	28·9	11·3	0·0	7·25	35·4	21·0	7·0	3·2	33·0	+4·4	3–4	6–6	6–8
X	6·1	6·3	33·5	69·0	4·20	29·55	11·5	0·0	7·20	35·60	21·2	7·2	3·1	31·0	+4·5	2–3	6–6	6–7

more or less uniform width between the head and the ganglion. A thick epidermis extends along its length showing a slightly larger thickening behind the head. The corona ciliata is limited to the anterior region of the trunk (Fig. VIII), and is hour-glass shaped.

The semi-elliptical and completely rayed anterior fin arises below the ventral ganglion, and is shorter than the posterior, which is broader and nearly one and a half times longer than the anterior fin. The distance between the two pairs of fins is appreciable. The seminal vesicle is like that of *S. bedoti* except that it does not reach the tail fin, and has the glandular and non-glandular areas not so well differentiated as in *S. robusta*. The triangular tail fin is fully rayed.

Distribution.—*S. regularis* was found in appreciable numbers in Calicut especially during the summer and early monsoon months, but was rare in the collections of the east coast.

9. *SAGITTA HISPIDA*, CONANT, 1895.

Sagitta hispida, Burfield and Harvey, 1926.

S. hispida is very rare in the Malabar plankton. The systematic position of this species was very much in doubt owing to the incompleteness and contradictory nature of the original descriptions and sketches. Burfield and Harvey (1926) redescribed it giving all the well-marked diagnostic characters of the species.

The head is cylindrical and is slightly broader than the trunk. The neck is inconspicuous. Body is translucent, narrow and greatly 'hispid' due to the presence of large number of tactile hairs which extend all over the body. The collarette extends half way to the ventral ganglion. The muscles are strong and do not shrink on preservation although the sensory hairs generally fall off. The ventral ganglion is very nearly reached by the anterior fin, but not by the collarette (Fig. 9). The elongated sinuous corona ciliata starts in front of the eyes and extends half way up to the relatively large and swollen ventral ganglion. The fully rayed anterior fin is narrow and short. The posterior fin is longer and broader than the anterior fin, and has more of its length lying on the trunk and never reaches the seminal vesicle as in *S. robusta*. The tail is roughly a fourth to a third of the total length of the animal. Tactile bodies are very distinct on the tail fin. The prominent seminal vesicle reaches the caudal fin.

Distribution.—*S. hispida* was obtained in small numbers from the Calicut coast in April and May. Two specimens were found along with *S. robusta* in the collections from the Gulf of Manaar.

Genus *PTEROSAGITTA*, Costa, 1869.

Syn. *Spadella*, Langerhans, 1880.
Pterosagitta, Michael, 1919.

1. *PTEROSAGITTA DRACO*, (KROHN, 1853).

Spadella draco, Aida, 1897; Fowler, 1906; Michael, 1911.
Pterosagitta draco, Ritter Zahony, 1911; Michael, 1919; Burfield and Harvey, 1926; Tokioka, 1939.

This species is described as an inhabitant of warm oceanic waters. Only 5 specimens* are present in my collections, of which one is from the Gulf of Manaar.

* One of these collected from Calicut was lent to me for examination by Mr. R. V. Nair to whom my thanks are due.

SAGITTA HISPIDA.

Table of percentage measurements.

Specimen Number.	Length in mm.	Width.	Length of tail.	Tail to ventral ganglion.	Length of ventral ganglion.	Posterior fin.					Anterior fin.			Collarette.		Number of anterior teeth.	Number of posterior teeth.	Number of prehensile jaws.
						Length.	Width.	To seminal vesicle.	To anterior fin.	Tail-septum.	Length.	Width.	To ventral ganglion.	Length.	To ventral ganglion.			
I	8·0	5·9	23·9	70·3	6·6	25·9	5·5	3·0	8·0	59·5	19·2	2·5	3·5	18·5	6·5	5–6	10–11	7–8
II	8·5	5·5	24·0	71·0	6·5	26·0	5·2	2·8	7·5	59·1	19·8	2·6	3·0	17·5	5·9	5–6	11–11	7–8
III	8·9	5·2	25·0	72·0	7·0	25·0	5·2	3·0	7·8	60·1	18·5	2·7	2·0	17·0	6·8	5–6	10–11	7–7
IV	9·0	5·0	24·8	70·0	7·2	24·5	5·0	2·8	7·2	58·9	18·5	2·5	2·0	18·2	6·0	5–5	10–11	7–8
V	9·2	4·8	24·9	71·0	7·0	25·1	5·2	2·7	7·5	59·5	18·9	2·7	2·3	18·5	6·0	5–6	11–10	8–8

PTEROSAGITTA DRACO.

Table of percentage measurements.

Specimen Number.	Length in mm.	Width with collarette.	Width without collarette.	Length of tail.	Tail to ventral ganglion.	Length of ventral ganglion.	Length of collarette.	Lateral fin.			Ovary.		Number of anterior teeth.	Number of posterior teeth.	Number of prehensile jaws.
								Length.	Width.	To seminal vesicle.	Length.	Width.			
I	4·6	16·1	7·5	43·0	65·2	8·5	75·0	22·5	7·2	0·0	..	..	8–9	15–16	8–8
II	4·8	16·6	8·1	41·6	63·0	8·0	75·2	23·0	7·5	0·0	..	..	8–7	15–17	8–7
III	5·0	16·0	7·5	40·0	70·0	8·0	78·0	21·0	7·0	0·0	9·0	1·2	8–8	15–15	8–8
IV	6·0	13·2	6·5	43·5	71·6	8·7	74·8	21·6	6·5	0·0	..	..	8–7	15–17	7–8
V	6·5	15·0	8·0	43·0	65·0	7·0	75·0	20·0	7·3	0·0	18·5	1·7	8–7	15–17	8–8

The body appears to be very broad due to the long and massive collarette which extends to the fin. Head is large and oval and the neck inconspicuous. The single pair of lateral fins is situated entirely on the tail segment. It is semi-elliptical, small and fully rayed. The collarette with its cellular structure spreads over the fin extending almost up to its posterior end. The triangular caudal fin is fully rayed. The seminal vesicle resembles that of *S. robusta* in being in contact with the fins. In mature specimens the ovary extends far up on the trunk rendering the region opaque.

The tail region is much longer than in any species of *Sagitta* being nearly half the total length of the animal (41·6 to 43·5%), but there seems to be considerable variations in the tail-body proportions (from 39·5 to 57%), judging from the records of Michael (1919), Fowler (1906), and Burfield (1926). The slightly curved prehensile jaws are faintly serrated on their inner edge. Except for two or three of the anterior-most teeth which are long and broader, the rest are all small. The posterior row has generally double the number of teeth than the anterior. A pair of bundles of large tactile hairs were seen on either side of the trunk at the level of the ventral ganglion in the specimen lent to me by Mr. Nair. Except for this peculiarity and except for its being small and immature it is like any other specimen of *Pterosagitta draco*.

Genus *KROHNITTA*, Ritter Zahony, 1911.

Syn. *Krohnia*, Langerhans, 1880 (part); Strodtmann, 1892 (part).
Spadella, Grassi, 1883 (part).
Krohnitta, Michael, 1919.

The genus is represented by two forms which are not very different from one another. Ritter Zahony (1911) and Michael (1919) consider that the difference between them is inadequate to justify their rank as independent species while Tokioka (1939) and Thomson (1947) prefer retention of both the species. Burfield and Harvey (1926) have recognised only one species, but with two forms, *K. subtilis* forma *typica* and *K. subtilis* forma *pacifica*, as the differences noticed are considered to be minor. Although the differences between the two are not very striking, some of the characters appear to be constant and independent for each species and since no intermediate stage has so far been obtained, the two forms are described here as two separate species.

1. *KROHNITTA PACIFICA* (AIDA) 1897.

Krohnia pacifica, Aida, 1897; Doncaster, 1903; Fowler, 1906; Varadarajan and Chacko, 1942; Pillai, 1945.
Krohnitta pacifica, Tokioka, 1939; Thomson, 1947.

This is the common species of *Krohnitta* of Indian coastal waters. The body is short and broad and the neck is very prominent. The head is slightly broader than the trunk. The collarette is absent. The top-shaped corona ciliata extends slightly downwards in the region of the neck. The prominent ventral ganglion lies halfway between the neck and the lateral fin. The fin rays generally do not reach the base. The fins on fixation have been observed in many cases to shrink considerably masking the original pattern. More of the fin is situated on the tail. The seminal vesicle is large, oval shaped and overlapped by the lateral fin. The ovary in mature specimens is long extending beyond the anterior end of the lateral fin. The tail fin is spatula-shaped and fully rayed. The prehensile jaws are curved at the middle and sharply pointed. The degree of curvature of the spines

KROHNITTA PACIFICA.

Table of percentage measurements.

Specimen Number.	Length in mm.	Width.	Length of tail.	Tail to ventral ganglion.	Length of ventral ganglion.	Lateral fin.				Ovary.		Number of teeth.	Number of prehensile jaws.
						Length.	Width.	To seminal vesicle.	Tail septum.	Length.	Width.		
I	5·0	6·5	31·0	64·9	6·8	34·3	6·5	0·0	37·5	14·6	2·6	11–13	8–8
II	5·2	6·2	30·8	64·1	7·0	34·5	6·7	0·0	37·5	15·5	2·5	10–13	8–10
III	5·25	6·0	31·1	64·2	7·0	34·6	6·9	0·0	37·2	12·8	2·6	11–12	9–10
IV	5·60	6·6	31·0	63·9	6·8	34·6	6·7	0·0	37·0	15·0	2·4	11–12	10–10
V	5·80	6·5	31·8	63·8	7·2	34·5	6·7	0·0	36·8	15·0	2·3	11–11	8–8

vary not only in different individuals but also in the individual jaws of the same specimen. Teeth are broad based and conically arranged.

Distribution.—Varadarajan and Chacko (1942) and Pillai (1945, abstract) have recorded this species from the east and west coasts respectively as *Krohnia pacifica*. This species is represented in most inshore collections on both the coasts of India, although it is more common in the offshore hauls, especially during March and April. Compared to the forms recorded from the Philippines and Japanese waters, the local forms are much smaller in size.

2. *KROHNITTA SUBTILIS* (GRASSI, 1883).

Krohnia subtilis, Strodtmann, 1892; Fowler, 1905 and 1906.

Krohnitta subtilis, Ritter Zahony, 1911; Michael 1919; Burfield and Harvey, 1926 (part); Tokioka, 1939; Thomson, 1947.

This species is very rare in the present collections. The body is longer and more slender than that of *K. pacifica*. The tail septum is very prominent. The paired fin is more round than oval in shape. The ovary is short and stumpy in all the specimens examined. The seminal vesicle is less pronounced.

The confusion that prevailed up to the first quarter of the present century in the systematic position of many of the earlier incompletely described species, due mainly to the lack of full realisation of the wide range of variations in the morphological features chosen as diagnostic characters, was gradually cleared through the efforts of Michael (1919) and Burfield and Harvey (1926). In assigning Doncaster's (1903) numerous species to their correct systematic positions, the latter have shown the importance of percentage measurements, and of the indication of the limits of variation of the length of collarette, of the size, structure and position of the anterior and posterior fins, and of the relative positions of the anterior and posterior fins to the ventral ganglion and to the seminal vesicles respectively.

The variations in the structure and length of the anterior and posterior pairs of fins have been made use of as one of the diagnostic features of *Sagitta*. For instance, the very long anterior fin in *pulchra* occupies more than thirty per cent of the total length of the animal, while, in *bedoti* and *planktonis* the anterior fins are longer than the posterior. In *enflata*, *regularis*, *neglecta* and *tenuis* the anterior fins are shorter than the posterior to a variable degree. In *robusta* the fin length is variable. According to Burfield and Harvey (1926) the relative lengths of the anterior and posterior fins in *robusta* are variable with equality between the two or slight inequality. The numerous combinations of fin length in *robusta* have been suitably illustrated by them with sketches and tables. If relative length of the fins alone is a distinguishing character many difficulties arise as for instance in the correct differentiation of *bedoti* from *robusta* which necessitates the use of other characters in the fins. The structure of the collarette and its relative position to the ventral ganglion and the anterior fin, the shape of the corona ciliata and its position in relation to the eye spots, the structure of the seminal vesicle and its relation to the posterior and caudal fins have been used in the classification of chaetognaths. The variation in the number of jaws and teeth on which Doncaster (1903) based his species have been proved to be unreliable by later workers as this character appears to be correlated with temperatures of warm and temperate waters (vide Michael, 1919). Thomson (1947) has shown that the relative length of the ovary in mature specimens can be used with advantage in the determination of species of *Krohnitta*, although this method has been found to be less suitable with preserved material due to opacity. Characters such as the percentage distance between the genital openings, the presence of thick epidermis, the presence or absence of sensory tufts of hairs, etc., have also been found to be unreliable.

KROHNITTA SUBTILIS.

Table of percentage measurements.

Specimen Number.	Length in mm.	Width.	Length of tail.	Tail to ventral ganglion.	Length of ventral ganglion.	Lateral fin.				Ovary.		Number of teeth.	Number of prehensile jaws.
						Length.	Width.	To seminal vesicle.	Tail septum.	Length.	Width.		
I	6·72	4·5	32·1	63·50	7·30	34·0	7·5	0·0	33·8	8·2	2·1	11–12	8–8
II	6·70	4·8	31·0	63·50	7·30	34·1	7·4	0·0	34·0	8·0	2·2	11–13	8–9
III	6·50	4·5	31·3	63·70	7·32	33·9	7·3	0·0	33·8	8·5	2·1	11–10	8–8

Seasonal occurrence of Chaetognatha in the Malabar Plankton

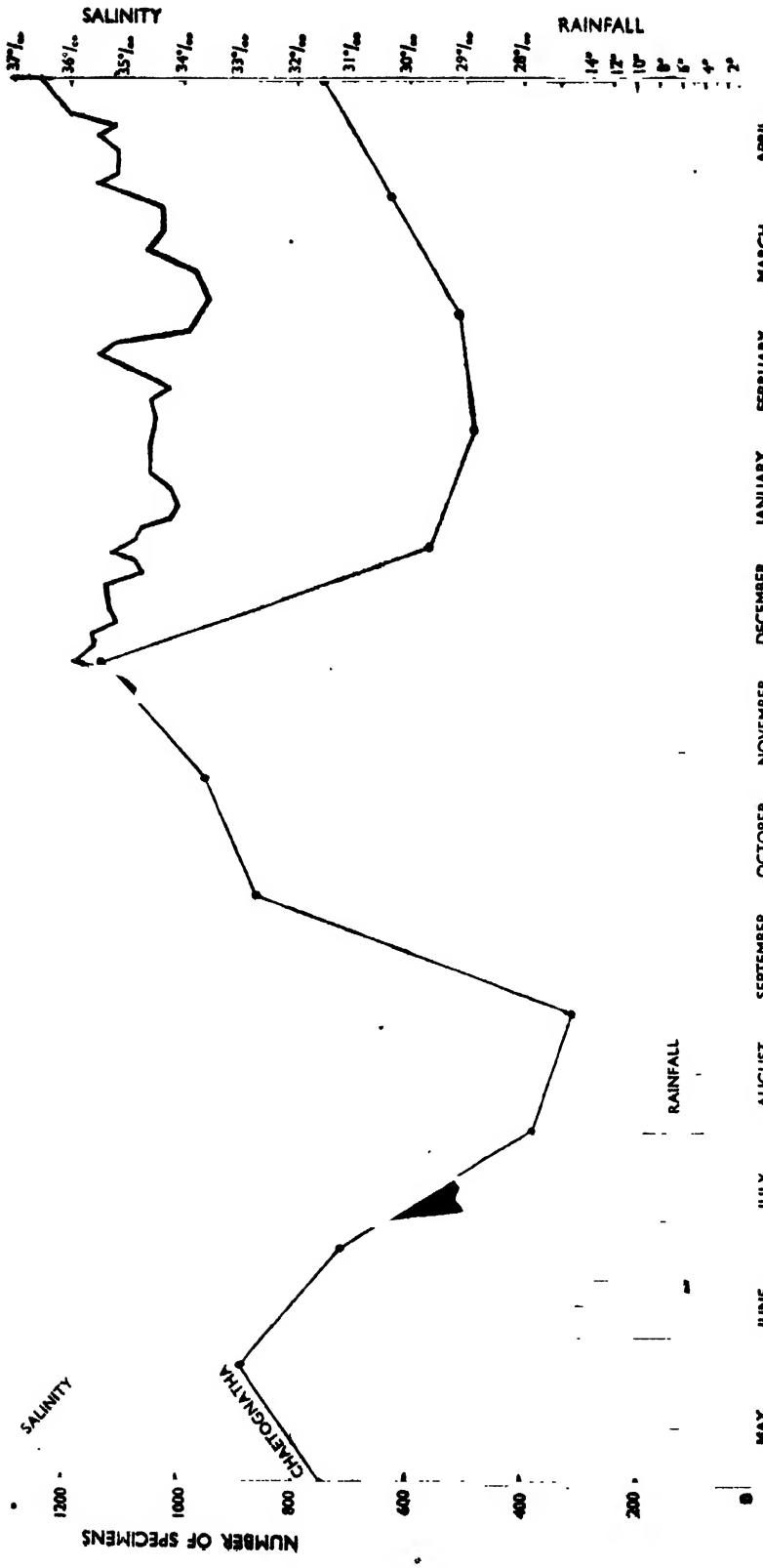
In the plankton off West Hill, Calicut, Chaetognatha, especially *Sagitta*, never failed to occur in the weekly collections, although there were marked variations in the relative abundance of the different species or in the presence or absence of any particular species in the different parts of the year. Figure 10 (Graph I) illustrates the fluctuations in the occurrence of Chaetognatha along the Malabar Coast and their correlation with salinity and rain-fall from May, 1948 to May, 1949. It shows two peaks of abundance, a major one—the *S. enflata* and *S. neglecta* peak in the October-December period, and a minor one—the *S. bedoti* and *S. robusta* peak from late May to early July. The former is probably due to the return of normal conditions in the sea during the post-South-West Monsoon period. There are two periods of scarcity of chaetognaths, that is, a pronounced one from end of July to the end of September, and a lesser one from January to March. The scarcity in the former is due to the sharp fall in the number of *S. enflata*, the commonest form of the coast, at this time of the year, and in the latter to the general reduction of population of arrow-worms on this coast.

The attached table of monthly percentage distribution of chaetognaths gives an idea of the conditions prevailing in the various seasons. With the break of the monsoon during the latter half of May there was a decline in *Sagitta enflata* which fell rapidly in numbers during June and July becoming very rare in the plankton during August. *Enflata* was replaced in May and June by *bedoti* and *robusta* which reached their peaks of abundance in June and declined steadily thereafter. *Tenuis* appeared in June and July. *Neglecta* and *regularis* were more or less uniformly distributed during the rainy season. *Pterosagitta draco* and *Krohnitta subtilis*, which were recorded in small numbers in May, disappeared during the rest of the period of the South-West Monsoon. While *neglecta* and *enflata* registered a gradual rise during September, *tenuis* and *bedoti* declined, the remaining species being unrepresented.

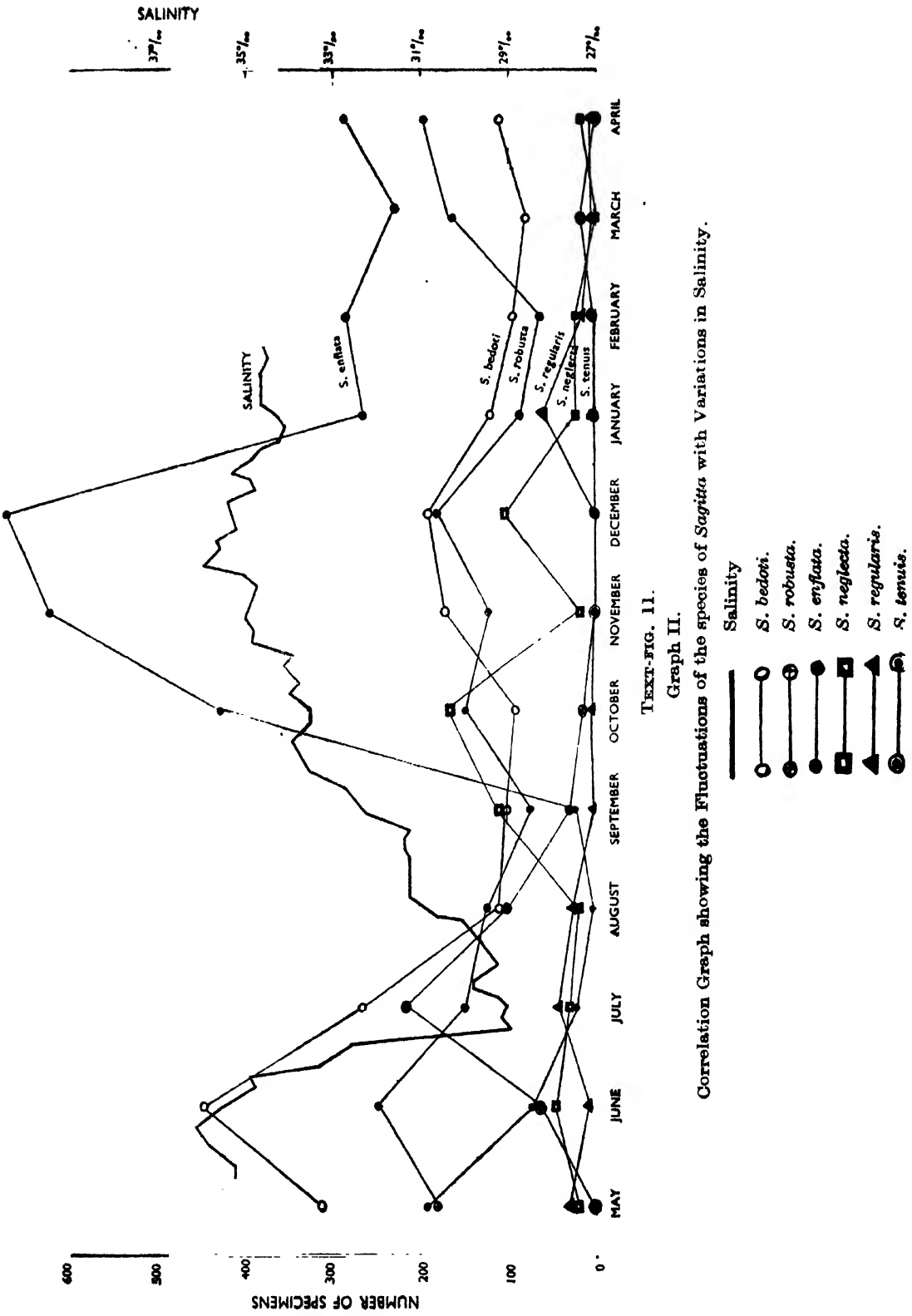
Chaetognaths reappeared in large numbers during October and almost all the species recorded during the year were represented maintaining the highest total for the month. *Enflata* collected in October was mostly immature and small and occurred in large numbers. It increased in numbers in November reaching its peak in December, and during these months it had attained a length of 24 mm. The *neglecta* peak in October was followed by a steep decline in November and a rise again in December. *Bedoti* and *robusta* also registered a marked rise from October to December. *K. subtilis* was common during October and fully ripe with the ovaries reaching the level of the ventral ganglion. Other species were rare during the cold months. During January, *regularis* attained a peak and was uniformly distributed in the succeeding hot months. Although the *enflata* peak was not attained till December, the species was well represented throughout the hot season. *Bedoti* and *robusta* were also abundant from January to April, the latter showing a minor peak in April. *Neglecta* and *tenuis* were few and the other species rare, during these months. (Text-fig. 11, Graph 11).

Hydrographical Factors.

An attempt has been made to correlate the seasonal fluctuations in the *Sagitta* population in the West Hill Sea with the salinity and temperature of surface waters and the rain-fall. The range of salinity was 36·64% in May to 28·88% in July. The salinity values fell rapidly with the onset of the monsoon and remained very low during June and July after which a slow but steady rise was noticed. They remained more or less steady during the occasional October-November rains. The variations in salinity in the coastal waters of Malabar are not unlike those observed in Bombay Harbour (Bal *et al.*, 1946). The poor North-East Monsoon was



TEXT-FIG. 10.
Graph I.
Seasonal Distribution of Chaetognatha with Reference to Variations in Salinity and Rain-fall.



TEXT-FIG. 11.

Graph II.

Correlation Graph showing the Fluctuations of the species of *Sagitta* with Variations in Salinity.

MONTHLY PERCENTAGE DISTRIBUTION OF CHAETOGNATHA, MALABAR COAST, 1948-49.

Species.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
S. enflata	25·90	8·50	3·40	0·71	5·10	50·80	65·10	54·00	47·60	51·00	46·70	47·00
S. bedoti	42·10	50·10	37·00	30·50	31·00	10·50	16·60	16·12	20·00	18·80	17·80	16·20
S. robusta	24·00	28·00	18·10	30·29	24·40	16·00	15·38	15·80	16·40	17·50	29·70	30·50
S. neglecta	3·20	5·20	3·60	3·80	34·20	18·50	2·90	13·90	3·50	7·02	..	2·60
S. tenuis	..	7·40	31·80	28·70	5·30	0·80	..	..	..	0·22	3·80	..
S. pulchra	..	..	..	..	..	0·35	..	..	0·30	..	0·02	0·30
S. planktonis	..	..	..	..	..	0·38	..	..	..	0·44	0·02	1·50
S. hispida	0·92	..	..	..	..	..	..	..	..	..	..	0·80
S. regularis	3·34	0·80	6·10	6·00	..	0·35	..	..	12·20	5·02	1·90	0·80
P. draco	0·01	..	..	..	..	0·12	0·02	..	..	..	0·02	..
K. subtilis	0·53	..	..	..	..	2·20	..	0·18	..	..	0·04	0·30

apparently responsible for the small change in the salinity of the inshore waters during the October-November period. The salinities were fairly stationary up to March when they began to rise to the maximum in the first week of May. Early and heavy pre-monsoon rains in the latter half of May maintained salinities and temperatures of the inshore waters at low levels for a period. A decline in the zoo-plankton elements and a gradual rise in the phytoplankton elements towards a peak were also characteristic features of this period. The sudden lowering of salinity and surface temperature results in curious changes in the composition of populations of Arrow-worms as for instance the complete disappearance of ***enflata*** and the attainment of a peak of occurrence in *tenuis*. As the graphs show, the salinity changes do not seem to affect the other species of *Sagitta* to the same extent.

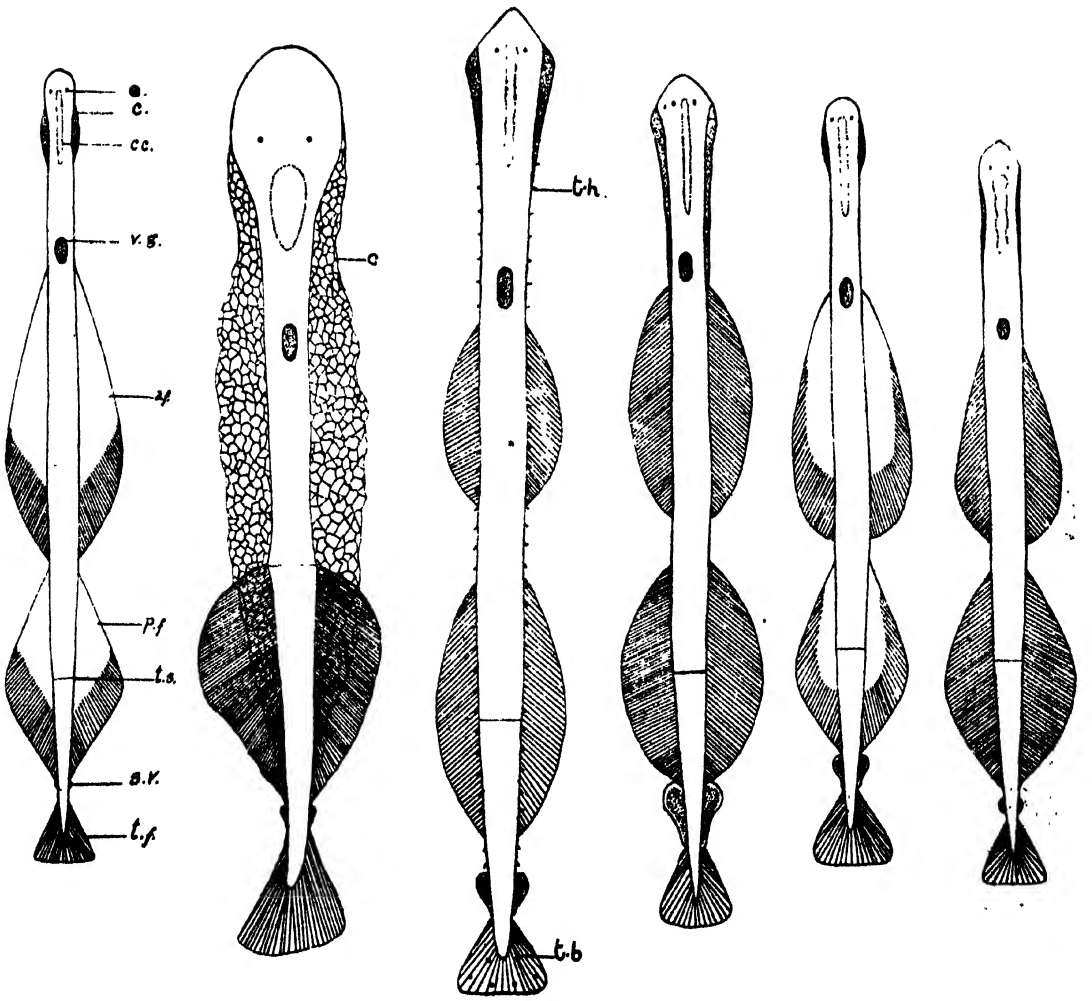
Discussion.

It may be seen from the foregoing account that arrow worms occur in the coastal waters of the West Coast throughout the year with a few periodical inter- and intra-specific fluctuations as shown in the tables and graphs, and the present contribution fully corroborates what has been observed already on the Madras Coast by Menon (1931) and Aiyar, Menon and Menon (1936). The present investigation based on triweekly collections over a whole year shows that although chaetognaths are represented in the plankton all the year round, there are periods of occurrence of maxima and minima as seen in the accompanying graphs. Whether these periods of abundance and scarcity have anything to do with the increase or lowering of salinities have not been elucidated beyond controversy (vide John and Subramaniam, 1937). The plankton of the Malabar coast during the October-December and May-June periods contains abundant chaetognaths with a major peak period for species of *Sagitta* in the former. In the peak that occurs after the South-West Monsoon the larger species, *enflata*, dominates, while in the minor peak during May-June the smaller species *bedoti* and *tenuis* dominate. *S. robusta* seems, however, more or less uniformly distributed in both the periods of maxima.

It is well known that the fluctuations in salinity and temperature are generally of the same pattern in all coastal waters (Sverdrup, 1942). According to Chidambaram and Devidoss Menon (1945) the surface temperature of the inshore waters of the West Hill coast reaches its maximum in March-April and its minimum in June-August. A similar maximum is reached in October. This is in a line with salinity readings recorded by the present author for the same region showing that the fluctuations in temperature and salinity are more or less similar. The histograms illustrating rain-fall on the West Coast in a whole year show that low salinities and temperatures prevail during the season of maximum rain-fall. The present investigation reveals that the chaetognath population in the coastal waters react in different degrees to these fluctuations. The distribution of *enflata* seems to follow closely the rise and fall of salinity. It becomes progressively scarce from May to early August, but in October it tends to rise again reaching a peak in December. This is in accord with the observations of Tokioka (1940) on ***enflata*** in the regions where the warm oceanic and cold or brackish waters mingle. Clarke *et al.* (1943) have observed on George's Bank that ***enflata*** occurred entirely outside the margin of the mixed area and that the species could not tolerate lower temperatures and salinities.

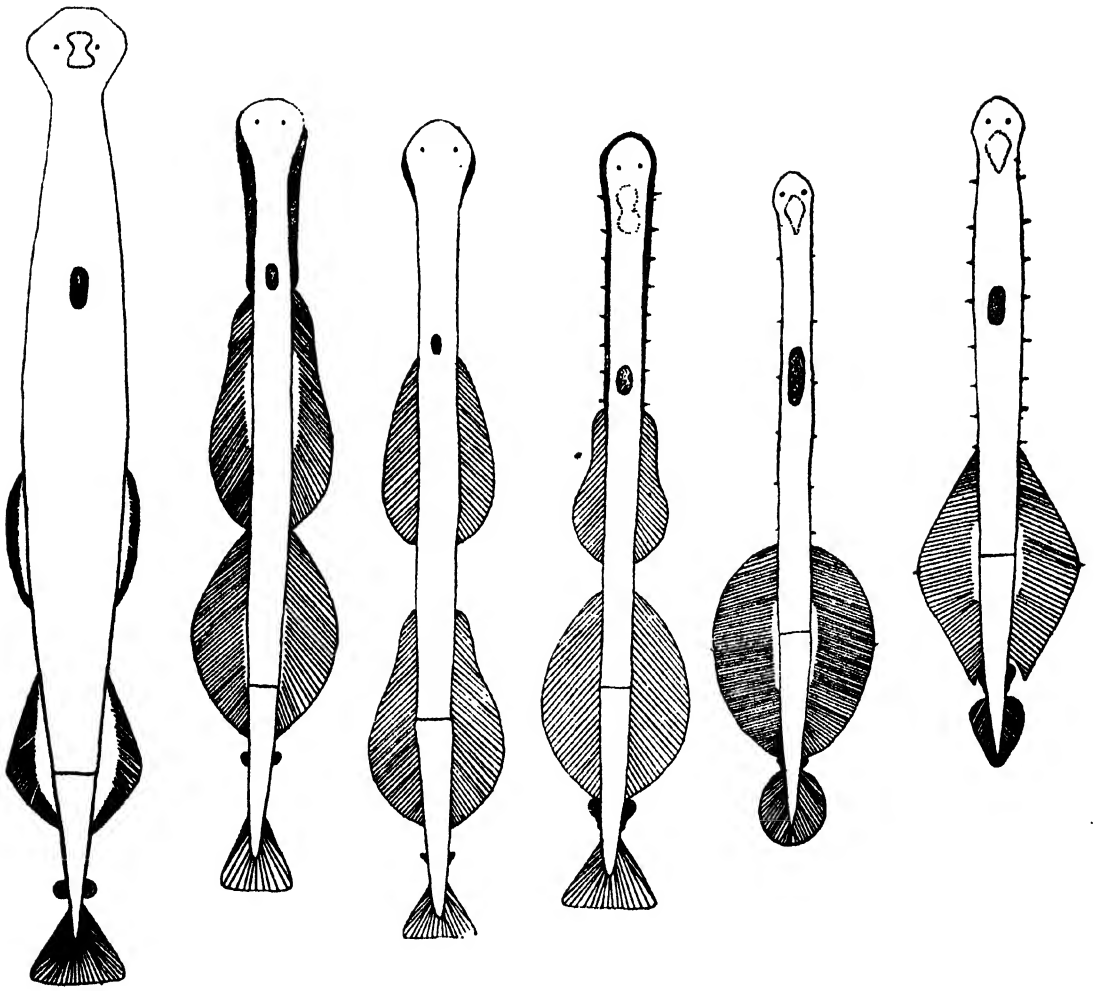
While ***enflata*** disappears almost completely from the surface plankton during the periods of low salinity and temperature, *tenuis* seems to take its place in coastal waters. *S. tenuis*, the smallest recorded species on the Malabar coast, is almost wholly limited in occurrence to the monsoon period. This is in agreement with the observations of Menon (1945) on the Trivandrum coast. *S. robusta* and ***bedoti*** have a more or less uniform distribution throughout the year. These and ***regularis***

TEXT-FIG. 12.



A *S. pulchra.* B *P. draco.* C *S. hispida.* D *S. robusta.* E *S. bedoti.* F *S. neglecta.*

TEXT-FIG. 13.



G *S. enflata.* H *S. planktonis.* I *S. tenuis.* J *S. regularis.* K *K. subtilis.* L *K. pacifica.*

appear to be less affected than others by sudden changes in salinity and temperature. The interesting suggestion, that the thick epidermis characteristic of these species may be one of the factors which make them less sensitive to the sharp fluctuations in salinity, temperature, and rain-fall, appears plausible (vide John, 1937).

The part played by the *Sagitta* of this coast as indicators of oceanic currents will apparently remain obscure until more information on the Indian Ocean currents affecting coastal waters is forthcoming. The sporadic occurrence during the monsoon season of large numbers of *enflata* in the 15 meter horizontal hauls of plankton seems to be correlated with the abnormal salinity, *p*H, phosphate, and silicate values recorded during the period, indicating the possibility of a sudden influx of oceanic water affecting inshore areas.

According to Hardy (1924) and Lebour (1921) *Sagitta* form a good proportion of the stomach contents of the European Herring, *Clupea harangus*. Varadarajan and Chacko (1942) and Chacko (1950) found arrow-worms in the stomachs of several clupeid fishes and mackerel. The investigations carried out at this research station on the food of mackerel for over a year indicate that arrow-worms constitute a rare inclusion among stomach contents even during periods of abundance of *Sagitta* in the plankton.

It is felt that with a more detailed knowledge of the ocean currents and the biology of arrow-worms of our seas than has been presented in this paper, it will be possible to interpret the significance of their distribution both in relation to their predators and the hydrographical conditions.

Summary.

The systematics of the common Chaetognatha of the Indian coastal waters is briefly discussed. Nine species of *Sagitta*, e.g. *enflata*, *bedoti*, *robusta*, *neglecta*, *tenuis*, *regularis*, *hispida*, *planktonis* and *pulchra*, two of *Krohnitta*, e.g. *pacifica* and *subtilis* and *Pterosagitta draco* are described with special reference to the body proportions which indicate the limits of variations. Keys to the genera and species of Indian Chaetognatha and a table of diagnostic features of Indian *Sagitta* are included. The seasonal variations in the distribution of the Chaetognatha of the Malabar Coast are discussed with reference to temperature, salinity and rain-fall. It is shown clearly that although Chaetognatha as a group occurs in our seas throughout the year the individual species have their own seasons of abundance and scarcity. The most noteworthy feature of the present study is that *S. enflata* cannot tolerate the lowered salinities of sea-water during the monsoon period. The need for further study of the habits of arrow-worms is stressed in view of their importance as indicators of offshore or oceanic water movements.

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KEY TO LETTERING.

a.f. .. anterior fin,
c. .. collarette,
c.c. .. corona ciliata,
e. .. eye,
p.f. .. posterior fin,
s.v. .. seminal vesicle,
t.b. .. tactile body,
t.f. .. tail fin,
t.h. .. tactile hair,
t.s. .. tail septum,
v.g. .. ventral ganglion.

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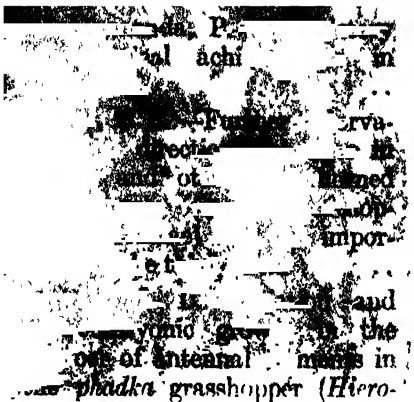

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